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AN EXAMINATION OF THE WEATHER GRAPHICS SYSTEM (DIGITAL FACSIMILE) ACQUISITION

RESEARCH REPORT

No. 504 **By** Nick G. Tulintseff

AIR WAR COLLEGE
AIR UNIVERSITY
UNITED STATES AIR FORCE
MAXWELL AIR FORCE BASE, ALABAMA

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by

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DISCLAIMER-ABSTAINER

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AIR WAR COLLEGE RESEARCH REPORT SUMMARY
No. 504

TITLE: An Examination of the Weather Graphics System (Digital Facsimile) Acquisition

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The acquisition of the Weather Graphics System for disseminating weather information to users worldwide is described and examined from beginning to end. The role and decisions of involved Air Force organizations are highlighted at critical decision points in the implementation process. The lack of technical judgment in assessing the risk of the connecting communications channel and its information capacity is apparent from the test results. A means to isolate the communications channel from the terminal hardware is suggested as a separate implementation task and should be applied to future communications-electronics acquisitions of terminal hardware.

BIOGRAPHICAL SKETCH

Lieutenant Colonel Nick G. Tulintseff, (M.S.E.E., University of Colorado) has been involved in the acquisition and operation of numerous communications-electronics systems since he was commissioned in the United States Air Force on August 19, 1955. He served in Thailand as the Commander of the 1982th Communications Squadron in February 1972-73 supporting the combat operations of the 8th Tactical Fighter Wing. Lieutenant Colonel Tulintseff completed a four-year tour at Headquarters United States Air Force prior to being assigned to Air University. He is a member of the Institute of Electrical and Electronic Engineers (IEEE) and a Professional Engineer licensed in the State of Washington.

PROLOGUE

The acquisition of communications systems which transfer and display information by electrical means is remarkably different in character from acquiring weapon systems such as military aircraft. By comparison, an aircraft becomes a separate entity once it is airborne. Aircraft systems and components are internal to the structural envelope, and the interfaces between subsystems are clearly defined. Distances within that structure are relatively short, and the environment can be controlled if necessary. Communications systems, on the other hand, usually cover large geographical areas. They may also interface with other domestic and foreign communications systems, commercial and military. A dilemma occurs when the terminal equipment operator does not control the transmission media. Furthermore, the transmission medium which provides the communications channel connecting the terminal equipments is subject to noise perturbations and human intervention for control. While the terminal environment can be controlled, and the information source and destination interfaces clearly defined, the communications channel continues to remain a variable process of nature and man.

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CHAPTER I

INTRODUCTION

Although this paper details the essential facts and implementation actions during the life of the Weather Graphics System (WGS) acquisition, its essential purpose is to examine the WGS acquisition results at critical decision points and draw meaningful conclusions that would improve technical management of future communications-electronics programs.

WGS is a facsimile (derived from Latin fac simile meaning "make similar") communications-electronics program for disseminating Air Force weather graphic information worldwide to Department of Defense users. A brief historical perspective follows in highlighting facsimile development. A general technical description of facsimile operation is provided in Appendix A.

Facsimile Historical Perspective

Daniel M. Costigan of Bell Laboratories has summarized the evolution and development of facsimile operation from a historical vantage point:

> Facsimile or "fax" as it became known flowered into a commercial reality in the mid-1930s, with a handful of experimenters. The use of fax as the transmission medium for worldwide transmission of photos by facsimile via wire and radio had been developed to a high degree of refinement. The Associated Press had, in fact, made such a

phenomenal success of its national "wire-photo" network, that four new development and manufacturing firms were formed almost simultaneously to meet the sudden demand for apparatus.

By the close of the thirties, there were nearly 40 commercial stations, regularly broadcasting fax newspapers, and by 1941, more than 10,000 fax receivers had been sold for home use--a phenomenal number for a single application, even by today's standards. However, by late 1940, there were definite signs of a declining public interest in fax receivers.

Meanwhile the United States had gone to war and the emphasis in fax development had shifted to military applications. In its new role, fax overcame some of its prewar shortcomings and matured sufficiently in the first three years of the war for the broadcasting industry to begin the next commercial phase of their experiment. The FCC consented to issue official operating standards and the second phase got underway about 1947.

Until late in 1949, there still seemed ample reason, in some quarters, to believe that fax radio newspaper was here to stay. But within a matter of months, whatever optimism still existed began to fade, and by early 1950, it was pretty much all over. The pioneers had misjudged the public's elusive tastes that facsimile and television could coexist.[1]

Background

The technology of the late 1940s was used in facsimile hardware procured for military service during the 1950s. At the direction of the Air Staff on April 11, 1955, to modernize the operation of Air Weather Service (AWS), a special development study group was established by Headquarters Air Research and Development Command, forerunner of Air Force Systems Command (AFSC).[2] The

results of this study effort were formalized into a program designated System 433L. This program was to introduce new equipments and techniques in an evolutionary manner to modernize the operation of AWS.

In November 1958, the Federal Aviation Agency (FAA) proposed establishment of a joint DoD-FAA-National Weather Bureau program with a single prime contractor responsible to the 433L System Program Office (SPO). After a review of the special development study previously mentioned, HQ USAF approved the operational requirement on January 13, 1959, for an improved military weather observing and forecasting system.[3] Shortly thereafter, the FAA proposal of a joint program was accepted by all parties and a work statement completed in February 1959. On July 17, 1959, the United Aircraft Corporation was selected as the system contractor. However, within a few months it became apparent that the goals and schedules of the participating agencies could not be mutually resolved. In December 1960, the FAA proposed to withdraw from the joint program and establish a separate effort but retain a coordination link with the Air Force for matters of mutual interest. The joint contract terminated March 30, 1961, and the Air Force established a new contract with United Aircraft Corporation to continue the implementation of System 433L.

The concept of System [illegible] operation was envisioned into three subsystems: weather observing, weather analysis and forecasting, and terminal equipment and presentation. The latter subsystem (terminal equipment) would function as the means for transferring weather graphic information from the analysis and forecasting center, known as the Air Force Global Weather Central (AFGWC) at Offutt Air Force Base, Nebraska, to users worldwide; hence its name, Weather Graphics System (WGS). The presentation equipment was to provide an improved means for a rapid on-base weather dissemination system and will not be discussed in this paper.

The weather map dissemination system that WGS was to replace consisted of four networks serving continental United States, Alaska, Pacific and Europe that had been operating since the latter part of the 1950s. The primary weather map information sources were located in England and Japan. The weather maps were transmitted over facsimile equipments designed for processing the information content using analog techniques. There were two facsimile models used by the Air Force. Model [illegible], manufactured by Litcom (forerunner of Datalog, division of Litton Industries) was primarily used in the continental United States, Alaska and the Pacific areas. Model [illegible], manufactured by Muirhead Limited of the United Kingdom

and known by the trade name Mufax was used exclusively in Europe from England to Spain and as far east as Turkey. The performance specifications of both models were essentially the same. The European Facsimile Network is shown in Appendix B.

Air Force leased the RJ-4 facsimile equipment from Datalog including depot service at the manufacturer's plant but with Air Force maintenance in the field. By contrast, Mufax facsimile equipment was entirely government owned. An Air Force refurbishment facility located at Frankfurt, Germany, provided the depot overhaul capability for Europe.

The RJ-4 equipments under lease were eventually replaced by an improved analog facsimile model DL-19W with a similar lease from Datalog starting in July 1974. The DL-19W model provided an information rate of twice that of its predecessor, the RJ-4, which in effect doubled the weather system's capacity over voice grade communications circuits.

The acquisition responsibility for WGS was assigned to Air Force Systems Command (AFSC) as the implementation command and delegated to the 433L SPO within the Electronic Systems Division (ESD). Participating commands were designated to assist in the acquisition of WGS. Military Air Command (MAC), and its subordinate

unit Air Weather Service (AWS), was the user. Air Force Communications Service (AFCS) was the maintaining command. Air Force Logistics Command (AFLC) was the materiel support command. Air Training Command (ATC) provided maintenance training. An agreement was reached between AFSC and the Ground Electronics and Engineering Agency (GEEIA) that the latter would provide technical services such as facility engineering and equipment installation. (As a matter of historical note, GEEIA was part of AFLC and was transferred to AFCS in 1970. The GEEIA functions were redesignated under the general title of engineering and programs within the AFCS headquarters management structure.)

Air Force Regulation 375 series (forerunner of AFR 800 series) and AFR 80-14 were the management and testing directives applicable to the acquisition of WGS. The test and evaluation program was a 433L SPO responsibility in assuring all concerned that WGS hardware would satisfy Air Force operational requirements.

Category I testing was controlled exclusively by the contractor, with government representatives participating as observers and test witnesses. The purpose of Category I testing was to assure that the prototype production model met all contract specifications and to establish a configuration baseline. Category II testing

was a joint contractor/Air Force effort conducted under government control with increasing operating and support command participation. Its purpose was to demonstrate that the system could function in an operational environment, meet the established contract specifications in the areas of performance, maintenance, safety and reliability with Air Force personnel operating and maintaining the equipment.

Category III testing was the responsibility of the using command after equipment delivery. The purpose of Category III testing was to refine deployment strategies, tactics and operational support techniques.

AFR 80-14 has now been revised and Category I, II and III testing responsibilities changed, redesignated and eliminated in the current regulation.

Communications Systems Elements

A fundamental understanding of the basic elements of a communications system--transmitter, communications channel, and receiver--is essential to the WGS acquisition described in the following pages. The three elements, their basic functions, and their relationships to the real world of equipment hardware are germane to this examination. The transmitter accepts the information input for internal processing (converts images to discrete or continuous information values) and encodes

the resultant information output. The receiver performs the inverse functions of decoding, information processing, and outputs to information display (hardcopy weather map facsimile). The communications channel connects the transmitter encoder to the receiver decoder by an interface called a modem (MOdulator-DEModulator). The communications channel actually includes part of the termination within the modem. The modem as an interface translates the encoder output information stream via a modulation scheme and is coupled to the termination within the modem out on the circuit to the distant end for the reverse information processing into the receiver decoder. The "information transfer" segment is the MOdulator-termination-circuit-termination-DEModulator whereas the communications channel includes only the circuit and the terminations. (The termination in reality is a matching device for maximum electrical information transfer.)

The term communications channel is used rather than "circuit" to emphasize the finite information transfer capacity of the channel. A practical circuit is perturbed by noise, signal attenuation and changes in velocity of signal propagation for different frequencies. Such a circuit when electrically terminated within the modem has a finite information transfer capacity or speed. This value depends upon two factors: a properly

designed termination and a modulation scheme. The information transfer segment is in reality a marriage between the right modem and the communications circuit. The information capacity of the resultant "information transfer segment" depends upon the quality of the circuit and the design sophistication of the modem. For a given quality circuit, increased channel capacity becomes dependent upon modem complexity and costs more. The termination networks in sophisticated modems feature adaptive automated equalization which dynamically minimizes circuit parameter perturbations that cause intersymbol interference. This allows higher data speeds to be transmitted than would normally be possible at a designated and acceptable error rate.

In summary, a communications system consists of terminal hardware that processes the intended information and matches the resultant information stream to the communications circuit for transmission to the receiver for the reverse processing and display to the user.

CHAPTER II

OPERATIONAL REQUIREMENT

In the opinion of many military communications and weather officers, a single set of hardware that would replace the ageing RJ-4s and Mufax equipment worldwide would achieve significant benefits. WGS was expected to increase the worldwide network capacity by speed alone, standardize equipments thereby reducing logistics costs, and provide savings on maintenance training. This appeared not only feasible, but logical, and the operational requirement began to take form. As a result, the requirement for WGS was approved in a November 3, 1964, revision to Specific Requirement Number 175, dated January 13, 1959.[1]

The approved operational requirement described the terminal equipment to be capable of reliable delivery of computer or manually originated graphical information to the distant terminals on inexpensive paper which is readily available and inexpensively reproducible. The minimum transmission rate within the continental United States and to overseas fixed facility users was to be equivalent to ten 18-inch by 36-inch charts per hour, and between fixed and mobile or remote area facilities equivalent to six 18-inch by 36-inch charts per hour.

The resolution of the input hardcopy would differentiate 100 lines per inch on the output facsimile hardcopy; for example, dissect the input copy as a matrix of black and white elements (PIXELS-picture elements) 0.01 inch on a side.[2]

Completion of all required engineering tasks was originally targeted for June 1966.[3] This new design was expected to increase weather graphic transmission rates by five to one over existing analog facsimile equipment in service.

The equipment quantities and completion schedules for WGS changed a number of times because of funding availability. Superseding 433L system program directives cited equipment quantities of thirty transmitters and 460 receivers which were reduced to twenty and 300 units respectively.[4] The completion date of fiscal year 1967 was changed to 1968.[5] Again, the completion date was slipped to fiscal year 1969 that all 433L would be operational.[6]

CHAPTER III

EQUIPMENT DEFINITION

The initial acquisition effort for WGS was to translate the operational requirement into a set of specifications for equipment definition. This required specifying the three elements of a general communications system; transmitter, communications channel, and receiver. The 433L SPO was to acquire the terminal transmitters and receivers that would operate over government provided communications channels/circuits through leases from commercial carriers and government-owned communications facilities. The WGS hardware would consist of two primary equipments and supporting test equipment with a short title "Weatherplotter Sets" and nomenclatured:

Transmitting Set, AN/GMT-3

Receiving Set, AN/GMH-5 (formerly AN/GMH-3)[1]

Government Proposed Specifications

The initial functional description issued by the SPO in coordination with AFCS and AWS provided that the transmitter set would digitize manually produced graphic products including geographical background data in the format utilized by the receiving set. The digital signal output of the transmitter would be recorded on punched tape for scheduled transmissions at either 1200 or 2400 bits per

second. The communications channel between the transmitter and receivers would be a voiceband circuit with a nominal bandwidth of 3000 cycles. The receiver graphic product rate would record in hardcopy not only an equivalent of ten 18-inch by 36-inch charts per hour, but simplified weather maps could lead to rates in excess of fifty charts per hour.[2]

To accommodate the weather information rate, the proposed government WGS transmission characteristics were as follows:

Signal to Noise Ratio: 26 decibels

Minimum Error Rate: 10^{-4}

Signal-Amplitude Modulated

Double sideband at 1200 bits per second

Quasi single sideband at 2400 bits per second

Data rates: 600 bits per second

1200 bits per second

2400 bits per second

Code: Baudot

Other than the bit error rate, the above characteristics were significantly revised in later actions which are described in subsequent chapters.

Communications Channel Specifications

An agreement was reached in March 1966 between AFCS, ESD(AFSC) and AWS for specifying the communications channel

parameters to support a WGS information transmission rate of 4800 bits per second. The communications circuit was to meet the technical requirements of an American Telephone and Telegraph (AT&T) Schedule C2 circuit or a Western Union Schedule F circuit. Schedule C2 or F did not include phase jitter, impulse noise, or harmonic distortion in the circuit technical specifications (see Appendix C). AFCS insisted that the request for proposal include phase jitter as part of the circuit specification.[3] Phase jitter is a significant factor in high speed digital transmission. The phase jitter parameter was also a design consideration within the terminal equipment for coupling to the communications channel.[4]

Equipment Specifications

The Weather plotter AN/GMT-3 transmitter and the AN/GMH-5 receiver specifications were described in terms of performance characteristics since it was assumed implicitly the engineering design was within the state-of-the-art. The design of the equipment became part of the technical proposals submitted by qualified bidders in the WGS procurement. The WGS technical approach is discussed in Chapter V.

CHAPTER IV

WGS PROCUREMENT

The WGS hardware was acquired by negotiated system procurement based solely on performance specifications.[1] By combining elements of the negotiation process with formal advertising procedures the two-step method provided the SPO an opportunity to explore, explain, and clarify the bidder's understanding and proposed means of satisfying the government's performance specifications.[2] This allowed the contractors time to fully reevaluate their proposals and to discover any errors. The approach encouraged innovation on the part of competing firms to develop new approaches, techniques and methods in the production of an item by not tying companies to existing processes or rigid specifications. In turn, the government expected to receive the benefit of industry's best technical efforts and would frequently obtain a significantly improved item.[3]

In negotiated systems procurement based purely on performance specifications, each proposer is free to offer his own specific design as long as it meets the performance criteria. Because of this, prices in negotiated procurements tend to vary much more than in advertised procurements. It also presents a risk to the

government in accepting the bidder's equipment design and expecting the system to satisfy operational requirements when finally completed. Thus the government by necessity relied on the company's reputation and technical expertise in the specific field of interest.[4]

Request For Proposal

A request for proposal was issued by Electronics Systems Division (AFSC) on October 27, 1966, calling for technical and cost proposals covering 20 Transmitting Sets, Weatherplotter; 125 Receiver Sets, Weatherplotter; data and assorted spares and test equipment. The request for proposal was amended on three occasions, November 9, 1966, November 30, 1966, and January 5, 1967. Four responses were received in March 1967 from the following firms:

Cardion Electronics, Incorporated	$5,296,675.75
EG&G, Incorporated	3,465,534.00
Litcom	12,630,283.00
United Aircraft Corporation	5,898,512.00

A review of the proposal prices by the government representatives showed the following: on the transmitter EG&G (Edgergon, Germasajusen & Greer) was second low bidder and $50,000 per copy higher than the government estimate; on the receivers they were low bidder by $9,000 per copy, but only $2,000 per copy lower than the government

estimate; on the data they were second low bidder and $210,000 higher than the government estimate. On the total price EG&G was low bidder but was almost $1,000,000 over the government estimate.[5]

Contract Award

Based on the bids, a firm fixed price contract (AF 19628-67-C-0347) was negotiated and awarded to EG&G in the amount shown above on June 2, 1967, with an effective date of April 28, 1967. The contractor stated in his March 27, 1967, letter that his proposal and addenda thereto made him fully responsive to the request for procurement, and thus reconfirmed his proposal statement that the effort was within the state-of-art and his capability.[6] A contract option for 300 additional receivers for $3.14 million was included which would expire 30 days after Air Force approval of the preliminary Category II Test Report.

CHAPTER V

TECHNOLOGY

The technical approach used by EG&G to satisfy the WGS performance specifications is summarized by Thomas M. Tyler, II's paper titled "Two Hardcopy Terminals For PCM Communications of Meteorological Products":

> These terminals introduce image coding, synchronization and reprographic practices altogether foreign to the conventional facsimile terminals now handling identical traffic over comparable networks and provide thereby a five-fold increase in traffic capability. They employ constant velocity electromechanical scanning and recording mechanisms operating asynchronously at a rate of 960 scans per minute. Both terminals contain variable length messages, one message per scan, describing the result of a two-dimensional compression algorithm operating on successive, contiguous scans. The receiver predicts that successive scans are identical and uses the incoming messages to correct this prediction. Data rate buffering is provided at the transmitter and receiver by incremental chart advance mechanisms which are slaved to the data demand and supply, respectively, of the 4800 binits/second (binary digits) communications channel.[1]

To realize the technical approach taken by EG&G to design and produce WGS equipment, it is helpful to review the technological advances made during the 1960s. An understanding of the emerging technology during this period should place in perspective the challenge facing both the WGS manufacturer and the Air Force acquisition managers. Advances were made in two broad technical

fronts, digital component fabrication and information theory.

During the 1960s, the calculator industry was providing the semiconductor industry with a market for high-volume logic parts. As a result of this demand, single chip logic devices became commonplace in many digital applications both military and commercial. The advantages of single chip logic devices were high packing density, low power dissipation, and improved reliability. Signal processing using digital techniques also offered economies over certain analog designs in achieving equal performance.[2]

Advances in information theory during this period included codes for error detection, error correction, forward error correction and self-synchronizing codes. The effect of these codes was to improve information transfer rates.[3] These coding schemes coupled with advances made in digital logic components permitted equipment realization in the practical world of economics.

A unique coding algorithm used in WGS was developed by Robert A. Scholtz for self-synchronization, which is of utmost importance in any communications system. The Scholtz code, allowing unequal word lengths, demonstrated that a substantial savings in average word length and

information rate could be obtained over other recently proposed codes having synchronization capability.[4]

Significant improvements were also being made in modern transmission rates in the late 1960s. High speed data over voice circuits were being advanced from 2400 to 9600 bits per second.[5] Much of the improvement to increased transmission rates was directly attributable to adaptive equalization techniques made economically feasible by digital integrated circuits and transversal filters (intersymbol interference).[6] The cost of modems with adaptive equalization was proportional to the designated transmission rate, since higher data rates required a better degree of equalization (reduce signal phase delay). The degree of equalization was proportional to the number of taps required on the transversal filter and the complexity of realizing the tap adjusting algorithm.[7]

EG&G elected to design their own modem for WGS rather than buying from an established supplier. At the 1969 International Conference of Communications, Allan B. Chertor's paper claimed that the WGS modem would achieve a spectral efficiency of two binary digits per cycle of transmission bandwidth.[8] This multiple speed partial response (connective coding)[9] modem featuring a unique single sideband modulation-demodulation system was

developed to eliminate the requirement for many costly filters.[10] Thus this approach was taken to reduce WGS production costs.

CHAPTER VI

CATEGORY I TESTING

The contractor, EG&G, had completed the design work and fabricated the production prototype terminal equipment for first article qualification in the first quarter of 1969. WGS Category I testing started April 21, 1969,[1] for qualification tests, reliability and maintainability demonstration, electromagnetic interference, and aerospace ground equipment compatibility.

The transmitter and receiver were operated in a back-to-back configuration through a simulated controllable parameter C2 telephone circuit. During the test, when phase jitter parameters of the circuit varied in excess of $\pm$ 7.5 degrees, the modem error rate exceeded allowed limits. This was corrected by an engineering change to the modem which was implemented and demonstrated to meet the allowable error rate.[2]

The reliability demonstration was stopped on July 19, 1971, as a result of an Air Force letter identifying three relevant failures in the receiver and transmitter. At the time the demonstration was terminated, a total of 1050 hours (out of 1500 hours required) had been logged on the system.[3] The Commander of Electronics Systems Division was briefed that corrective action would result

in a one to nine month slip in the schedule from the completion date of January 1971. The documentation showed that the last of the twelve segments that comprised the complete Category I Test Report were approved 10 August 1972; they were AN/GMH-5 receiver qualification, AN/GMH-5 and AN/GMT-3 compatibility, reliability demonstration, electromagnetic interference and the modem and hardcopy error tests.[4]

CHAPTER VII

WGS CATEGORY II TESTS

Circuit Quality

Concern and some doubt were beginning to surface among HQ AFCS personnel regarding the ability of the WGS to operate satisfactorily over actual real world communication circuits because of the Category I test results. It was believed that the European military circuits could only support a 2400 bit per second data rate. At a meeting held at HQ AFCS on 13 January 1972, with representatives from AWS and ESD, it was agreed to establish a European demonstration vice the original continental United States demonstration prior to actual production delivery of WGS equipment. Such a demonstration would provide lead time to initiate action necessary to upgrade the European circuits to support a 4800 bit per second data rate.[1]

Category II Testing

WGS Category II equipment testing started on February 28, 1972.[2] The test required that the contractor supply a C2 conditioned communications loop of at least 1000 miles that terminated at the telephone mainframe at Hanscom Field. AFCS would provide the cable pair from the mainframe to the Category II test site and continue to meet C2 circuit conditioning.

The C2 circuit was provided to EG&G by the New England Telephone Company. On March 22, 1972, the 433L SPO notified AFCS and the AWS that the WGS modem would not operate adequately over the C2 circuit. EG&G was directed by the SPO to pursue and install changes necessary to the modem in order to overcome incompatibility between present telephone specifications for impulse noise and the current equipment specifications. AFCS was also requested to identify improvements which could be obtained in circuit signal to noise ratios.[3]

The C2 circuit provided by New England Telephone Company was experiencing an unusual number of dropouts (momentary loss of line). The phone company admitted that the problem was in the local lines between Hanscom Field in Bedford, Massachusetts, and their microwave transmitting facility on Franklin Street in Boston. They also admitted that it was difficult to provide a good line to Hanscom Field, and indicated that they were in the process of setting up a new line for the test at Logan International Airport in East Boston, Massachusetts.[4]

The improved WGS modem operation was obtained at a cost of $301,700.[5] On July 31, 1972, the WGS equipment was moved from the Category II Test Site at Hanscom Field to the New England Telephone and Telegraph Company power plant located at Logan International Airport. The WGS

modem was then successfully demonstrated, the operational tests completed on August 5, 1972, and the report approved by ESD August 10, 1972. This committed EG&G contractually to meet upgraded circuit specifications (five decibels signal to impulse noise ratio).[6]

In terms of output graphic products for Category II testing, the chart reception was only 52 percent acceptable overall and only 58 percent acceptable in the best mode of operation (tape transmission).[7]

Category II Test Observations

An AFCS engineer present at the Category II Tests noted that the back-to-back WGS reproduction of the AWS type of weather maps was not significantly superior to that reproduction of the same maps by analog equipment presently used in the field.[8] This illuminated a need for finding a grading scheme that would indicate the acceptability of digital test weather charts.

The same AFCS engineer attended a meeting April 4, 1972, with representatives from Rome Air Development Center (RADC), EG&G, ESD, and AWS regarding WGS modem impulse noise susceptibility. It was noted that the RADC representative said that the state-of-the-art for modem susceptibility to impulse noise was 10 to 15 decibels better than for the EG&G modem. It was pointed out that this state-of-the-art modem also costs more.[9]

It was noted at the same meeting that an RADC tested modem, most similar to the WGS modem, had two apparent improvements; it incorporated a proprietary error correction design applicable to partial-response modulation and, it used a 29 tap delay-line equalizer compared to 9 taps on the WGS delay line. EG&G had developed an engineering model expanding to 13 rather than 9 delay-line taps. The EG&G engineer indicated the 13 taps would result in satisfactory performance on a C2 specified circuit.[10] The 13 equalizer taps were the maximum possible without providing a new delay line.

Air Weather Service approved the April 4, 1972, meeting minutes subject to adding that the quality of facsimile weather maps would be graded either acceptable or unacceptable; for example, no marginal category, and that the WGS standard should be not more than three percent unacceptable of the total graphic products.[11] The contractor remarked that grading of maps should be against a criteria of "operational usability," rather than 100 percent readability.[12] The contract specification requirement for errors was that there should be no more than one communications error in 10^5 bits, and that one communications bit error should affect no more than two square inches of hardcopy on the average.

Because of the Category II tests, AWS needed to define the criteria for acceptable graphic products (since the test chart grading process was their responsibility). Each test chart contained 2570 alpha-numeric characters and minus signs. The unreadable characters were identified and subtracted from the total number of characters. This difference relative to the total number of characters was called the readability ratio and expressed as a percentage. The minimum acceptable readability value for these tests was designated to be 97.5 percent or precisely 64 unreadable characters.

CHAPTER VIII

EUROPEAN DEMONSTRATION

The purpose of the European demonstration was to determine the operational performance of the WGS over various circuits supporting United States Air Forces in Europe (USAFE) units, and was in essence an extension of Category II testing. The evaluation was expected to identify what circuit improvements, if any, needed to be made to support a WGS deployment throughout Europe.

While the Category II tests were in progress, AFCS personnel were busy conditioning military circuits in Europe for the WGS demonstration. Their efforts were not entirely successful due to many support problems that impinged upon achieving an equivalent C2 circuit conditioning.[1] As a result, not all circuits could be brought up to Defense Communications Agency standards of S2, which equalled or exceeded AT&T C2 circuit parameters (see Appendix C).

The European WGS demonstration was conducted during September 1972. The facsimile transmitter and receiver were installed at Lindsey Air Station and Rhein-Main Air Base respectively. The communications circuit between the transmitter and receiver was varied in length by loopback routings within the European portion of the

Defense Communications System (USAFE Microwave and 486L Mediterranean Tropospheric Communications System). Such loopbacks were made at Feldberg, Germany; Martlesham Heath, England; Hillingdon, England; Mt Vergine, Italy; Torrejon (Humosa), Spain; and Ankara (Elmadag), Turkey.

The WGS European demonstration failed to meet AWS requirements that 97 percent of all maps must be received 100 percent readable.[2] It was apparent to all concerned that the phase jitter variations and impulse noise levels of the main trunk routine within Europe were so high that WGS could not be deployed overseas successfully.[3]

CHAPTER IX

POST CATEGORY II DECISION PERIOD

The Air Staff, having been notified by AFSC of the WGS Category II and European demonstration test results, convened a meeting November 14-15, 1972, at the Pentagon. The purpose was to discuss alternatives ranging from total rejection of WGS to total acceptance of the entire option buy.[1] Both AWS and AFCS were to provide their rationale for nonconcurrence with the Category II Test report. Previously on November 7, 1972, EG&G was notified they had satisfied the contractual requirements of the WGS Category II test.[2]

At the Pentagon meeting the single AFSC representative recommended that the option buy not be exercised and that further investigation and testing over real world circuits be accomplished before considering further receiver procurements. Both MAC (AWS) and AFCS representatives concurred. AFSC was then directed to lead this investigation and prepare a draft plan by December 1, 1972. MAC (AWS) was requested to provide the minimum operational performance factors to support the proposed concept of operations in the plan.

At a 433L WGS meeting at ESD on November 28-30, 1972, representatives from AWS, AFCS and RADC (Rome Air

Development Center) discussed the possible solutions to overcoming the real world circuit problems. The idea of using forward error correction (FEC) techniques to improve the WGS performance was discussed by both AFCS and ESD earlier. The AFCS position was that FEC would allow WGS to be used within the continental United States but not overseas.

ESD's position was that 200 additional receivers would be needed for deployment to meet the total continental United States requirements. The $1.5 million currently allocated for the option buy of 300 receivers would probably cover the cost of 200 receivers and the FEC devices. ESD also believed that WGS with FEC would operate satisfactorily overseas if the phase jitter variations could be reduced.[3] The addition of the FEC would reduce the effective WGS speed from 5:1 to approximately 2.8:1 relative to the present 120 scans per minute analog facsimile terminals.

Another alternative discussed was to reduce the degree of information encoding by using forced absolute run length (FARL) with FEC. FARL would limit the propagation of an error bit or short error burst to one-third of a single scan line.[4] This in effect would reduce the data compression (coding of redundant data) and for a maximum transmission rate also reduce the information output rate in terms of speed advantage.

AWS agreed to reduce their weather map transmission rates for Europe only to three times that of the present analog facsimile system. However, this was later clarified to be an interim speed.[5]

AFCS decided to hedge their dependence upon WGS as the Muirhead replacement in Europe by taking separate programming action. On December 29, 1972, AFCS initiated an emergency implementation program action that would seek to replace the Muirhead analog facsimile terminals with an analog off-the-shelf system with a transmission speed increase of two over the present system.[6]

The Air Staff decision not to exercise the WGS receiver buy option and the AFCS concern regarding logistic supportability of Muirhead facsimile equipment which was more than twenty years old became the constraints limiting further WGS testing and deployment to Europe.

Another decision factor was the AWS draw down in Europe with the disestablishment of the European Weather Central at Croughton (likewise the Pacific Weather Central at Fuchu Air Base). Weather maps for US military units that had been transmitted from Croughton would now be sent directly from the Air Force Global Weather Control (AFGWC) at Offutt AFB.

CHAPTER X

WGS EUROPEAN TEST

Plan

The Air Staff on January 29, 1973, authorized AFSC and AFCS to proceed with planning for a WGS European Test. The test objective was specified to ascertain the actual maximum capability of WGS to operate over existing communication circuits.[1] The March 3, 1973, European test plan was to consist of two phases: Selection of FEC and the European Operational Test, commonly referred to as the "Signature Tests" and "Mini-Net" respectively.

The WGS modem limitations would be identified by a routine RADC modem comparison test and corrected by the contractor. Subsequent tests on the WGS modem would simulate medium to worse case European channels (tapes provided by AFCS) in the RADC Digital Communications Experimental Facility (DICEF) together with error tapes derived from the "Signature Tests." The simulations would serve as the basis for evaluating and selecting the best forward error correcting codes and run length compression methods for WGS.

The "Mini-Net" with the installed FEC in three AN/GMT-3 transmitters, 14 AN/GMH-5 receivers and six

regenerative units would be deployed to Europe in an operational environment. The use of regenerator units was considered in anticipation of excessive data error rates for Mediterranean sites. The transmitting signal would originate at AFGWC, Offutt AFB (two transmitters and one monitor receiver).

Test Approval

On March 23, 1973, the Air Staff approved the implementation of phase one only of the March 3, 1973, WGS European test plan, but with additional guidance. Phase one tests were to permit comparison of analog and digital charts, provide a spectrum of digital chart quality under various speeds and FEC devices, to include use of FARL, and a cost comparison evaluation between WGS and analog systems.[2] Phase two for the "Mini-Net" was considered too expensive ($785,000) by ESD for implementation and the Air Staff agreed.

Test Measurements

The actual measurement tests were performed during August 6 and September 9, 1973, and supervised by an ESD Test Director. The two test teams were comprised of AFCS and EG&G electrical engineers. AFCS was responsible for providing and aligning circuit conditioning equipment. EG&G technical personnel performed the transmitting and receive site measurements and recorded the

WGS modem decoder output on magnetic tape for later data reduction. The modem decoder output was recorded because it regained synchronism quickly due to the Scholtz-Hamming code words rather than using the pseudo random pattern synchronizer which occasionally would lose synchronism and result in large false error counts.

The WGS modem tests used a pseudo random code generated at the transmitter site. The resultant signal, perturbed by the communications circuit, was recorded at the receiving WGS modem decoder between the following locations:

Transmit	Receive
Offutt AFB	Croughton RAF
Croughton RAF	Upper Heyford RAF Zweibrücken AB Mildenhall RAF Hahn AB Zaragoza AB Incirlik AB Athenai AB

Since the bit error rates for the Mediterranean site were measured in excess of 10^{-3} and would result in unacceptable weather graphics products to the user, the need for digital data regeneration sites was confirmed. Additional WGS modem recordings were made to evaluate later by simulation the placement of signal regenerators in Europe. To support this evaluation, WGS modem decoder recordings were obtained for the links shown below:

Croughton RAF	to Ramstein AB	
	to Mt. Corna, Italy (Major Relay Site)	
	to Mt. Pateras, Greece (Major hub to Athens and Turkey)	
Ramstein AB	to Croughton RAF	
	to Mt. Corna, Italy	
	to Mt. Pateras, Greece	
Mt. Corna	to Mt. Pateras	

Daily test periods were established by AWS to record the digital data, to measure the circuit parameters, and to transmit two test charts via the existing analog facsimile system. The seventy (70) minute test periods were scheduled for 0040Z, 0700Z, 1340Z, and 1900Z, to provide a representative sample of circuit changes during the day. The goal was to collect twenty tapes of data per receiver site. To show the effects on the data of high level activity over the communications circuits, AFCS requested that Wednesdays, Thursdays and Fridays be included in the twenty periods.

Pseudo Operational Evaluations

A total of 185 tapes were recorded on sites representing 86 transmission hours, of which 137 tapes contained useful data.[3] The remainder were site test tapes, tapes during which setup problems were encountered, and tapes inadvertently erased because of tape transport malfunctions. In this latter category it was discovered that thirteen of the fifteen pseudo random code tapes recorded

at Incirlik Air Base, Turkey, were accidentally erased. One of the two remaining tapes from Incirlik was an unofficial checkout run. ESD convoluted their three worst error recordings onto a single error introduction tape assuming that a typical circuit to Incirlik would not exceed these limits. As a user, AWS considered the signature test data obtained at Incirlik a key indicator whether WGS equipment could be made usable in European deployment.[4]

It should be reemphasized that processing the signature test tapes was accomplished by the contractor EG&G. The field tapes containing the perturbed pseudo random code were reduced by an analysis computer with error determination, clock error detection and resynchronism performed by program algorithms. This process distinguished modem and circuit induced perturbations from on-site data reduction methods. The resultant computer output produced a binary zero for a correctly received bit and a binary one for an incorrectly received bit and were designated as "error introduction tapes" (EIT).

The EIT were used to evaluate various FEC capabilities and FARL as configured for European operation. A WGS transmitter and receiver were connected in a back-to-back configuration. Simultaneously applied to

the output of the WGS modem decoder (now bypassed) was the error output of the EIT (using an "exclusive or" function) perturbating the incoming standard test chart data stream to the receiver but being corrected to some degree by the inserted FEC function and the error propagation limited by the addition of FARL. The performance was then determined by the quality of the output graphic product in terms of the readability ratio.

The final pseudo operational network configuration simulated weather graphic reception in England, Germany, West and East Mediterranean using EIT recordings. The evaluation required the grading of all weather maps received at:

Upper Heyford RAF

Mildenhall RAF

Zweibrücken AB

Hahn AB

Incirlik AB

Zaragoza AB

The EIT recordings did not include the effects of burst errors and the simulated performance of the European network did not reflect this degradation in acceptable received maps.[5] The simulated performance also did not account for the degradation that would be incurred in transmission from Offutt AFB to Croughton RAF or Ramstein AB.[6]

The results of the WGS back-to-back operation using the EIT indicated a significant difference in readability performance between the European and Mediterranean receiver sites. The tests also showed the 3/4 Viterbi FEC was not competitive with the 3/4 and 2/3 convolutional FECs. Because of lower throughput and lesser readability ratios, the 2/3 FEC was rejected leaving the 3/4 FEC for consideration.

Conclusions

The ESD test report conclusions were the result of the pseudo operational evaluation using the error introduction tapes derived from the "Signature Tests." The results were tabulated for Croughton, England, Germany, Zaragoza, and Incirlik for 3/4 FEC only, FARL only, existing analog facsimile system versus the number of acceptable charts, throughput advantage for 97.5 percent readability and 100 percent readability.[7]

The test report concluded that the data from the European modem signature recording effort demonstrated that:

> The FARL configuration will produce facsimile charts over northern European communications links with 88% of the charts attaining a 100% readability ratio. 93% of the charts will have a readability ratio of 97.5% or better. The speed advantage over the existing analog system is 4.12 (3.99 is the maximum value in the tabulation).

To optimize the digital facsimile system using FARL, the signal must be regenerated by the WGS equipment at several intermediate links in the communications chain. Test data /more accurately the pseudo operational evaluation--added by author/ has shown that about 73% of the charts produced in this manner will have a readability ratio of 97.5% or better at the very extremities of the communications chain (Incirlik and Zaragosa). Optimizing the location of the regeneration site should improve this figure.

Modifying the system with a 3/4 rate convolutional forward error correction (FEC) device enhances the quality and appearance of many of the received products. For example, the data indicate that Incirlik can expect to receive approximately 83% of the charts with a readability ratio of 97.5% or better in this configutation. These improvements (including regeneration) will increase modification cost over the FARL configuration by about $375,000 and reduce the speed advantage over the analog system to 3.15 to 1.

When communication circuits are out of specification in regards to phase parameters, but better than specification in amplitude and noise parameters, analog facsimile will demonstrate a better readability ratio than the digital system. (Note: In half of the test periods, at least one of the measured circuit parameters did not meet the specification).

Retransmission of charts, especially to the Mediterranean, will be necessary to meet a criterion of 100% readability. If this criterion is to be met, the Mediterranean sites will require most of the retransmission, and analysis of the data suggests that the speed advantage of WGS will be reduced by some 20-25%. In all but the worst cases, the FARL WGS provides the better throughput capability.[8]

In this report, the AFCS test team concluded it was not feasible to maintain all circuits to S2 parameters

due to existing communications equipment characteristics and inadvertent changes to circuit routings. Although the circuit phase jitter per link was within tolerances (four degrees per link), its cummulative effect between end terminals exceeded allowable limits of the WGS modem (15 degrees).[9]

CHAPTER XI

WGS EUROPEAN TEST REPORT REVIEW

AFCS reviewed the WGS European Test Report submitted by ESD for coordination and issued a formal nonconcurrence.[1] AFCS objected to the ESD conclusion that forward error correction was unnecessary. Further adjustment of AWS standards which considered both test results and maintainability/repair factors would be needed for AFCS concurrence. AFCS requested that changes be made to the report conclusions and added the following:

> Test results demonstrate that the existing design goal of a five to one speed increase over analog, with a readability of 100 percent in 97.5 percent of the maps cannot be met with any WGS configuration (FARL or FEC/FARL, both with regeneration at the test locations) over the existing circuits.
>
> (FOR CSAF) AFCS believes that if the WGS equipment is to be deployed, a 3/4 convolutional coding forward error correction capability is a requirement. Furthermore, the WGS should be turned over as a system instead of a collection of black boxes.[2]

AWS reaction to the report was to recommend that WGS be considered deployable to Europe only if: the optimum operational configuration is selected, a single configuration and speed is deployed throughout Europe, AFCS agrees to fix the phase jitter in those facilities and circuits that they own before WGS goes operational,

and since WGS is yet to satisfactorily pass an operational test, a dual WGS-analog network be operated for 90-100 days as WGS is being installed. This would verify satisfactory operation in Turkey, Spain and Greece. With these stipulations AWS would agree to set new performance standards for assessing the European WGS.[3]

The ESD position was that the European tests clearly showed the limiting factor to be communication circuits and equipments, not WGS. They also stated it appeared that it was not cost effective to employ FEC throughout the entire network.[4]

A 433L program review was held at ESD on 6 February 1974. Agreement was reached that:[5]

FEC/FARL and regeneration was necessary.

System standards would be developed by AFCS/AWS.

Single hardware configuration was acceptable.

Dual analog-digital operation was a user's option.

ESD's primary concern now was to obtain quick CSAF direction, since EG&G was approaching several key decision points (termination of storage contract, and so forth).[6] HQ USAF indicated that the 433L Program Management Directive would be revised as necessary including assigning AFCS the responsibility of system engineering to accommodate the WGS installation. Procurement funds were being provided to AFSC for the WGS effort and

$150,000 made available to AFCS for WGS unique procurement requirements.[7]

Another factor in the WGS acquisition and deployment schedule was the logistic supportability of the existing analog facsimile network of Muirhead equipment. Action was taken to procure sufficient spares to maintain operation until the end of 1975 or the beginning of 1976. Spares support into 1977 was also under consideration depending upon progress of the WGS acquisition.[8]

CHAPTER XII

FINAL WGS OPERATIONAL TEST

Approval was received April 16, 1974, from HQ USAF to proceed with the WGS implementation in Europe (See Appendix D). An initial operational capability was set for December 1975 and sufficient funds were made available to the 433L SPO for the WGS modification.[1] A letter contract was awarded EG&G on May 2, 1974. The contract negotiations were completed July 19, 1974, for $808,500 and a signed contract returned to ESD on August 12, 1974,[2] for modification and packaging of:

114 Receivers

101 Receiver Test Sets

8 Transmitters

10 Regenerator/Receivers

10 Regenerator Test Sets.

AFSC notified AWS that their position for the implementation of WGS in Europe was for turnover to occur upon a functional demonstration and final delivery of hardware. The 433L SPO was of the opinion that turnover and the resultant documentation should not be dependent on, or constrained by, the equipment's performance in Europe since it was not an ESD responsibility.[3] This view was counter to the responsibilities assigned to

ESD(AFSC) in the program management directive issued by HQ USAF.

By October 15, 1975, all WGS equipment had been modified and shipped to Europe for installation by AFCS. During September 1975, AFCS with the assistance of ESD and EG&G performed operational tests between Kindsbach and Rhein-Main Air Base in Germany. Results of the test were disappointing. WGS did not meet the AWS criteria for Germany that 95 percent of the transmitted weather maps be 95.5 percent readable. The test was terminated on September 15, 1975. Subsequently, in October 1975, a moratorium was declared by AFCS on all further installation of WGS equipment pending further guidance from HQ USAF.

CHAPTER XIII

WGS PROGRAM TERMINATION

October 1975 Conference

Shortly after the termination of the WGS operational test between Kindsbach and Rhein-Main, and the AFCS installation moratorium, a conference was convened at HQ ESD during October 2-3, 1975.[1] Attendees included representatives from HQ USAF, AFCS, ESD, AWS, ATC and the contractor EG&G. The purpose of the conference was to determine a course of corrective actions for WGS.

The AFCS and ESD positions expressed at the conference were inconclusive in initially determining what course of action should be taken. The AFCS Program Manager briefed that WGS might require special nonstandard equalized circuits for optimum operation. Also the cause of a number of mechanical failures during the tests could not be traced to improper maintenance, nonperformance of regular preventive maintenance, or actual equipment component failures.[2] The ESD position was that inadequately trained personnel were in the field. They also felt the test performed in Europe did not provide conclusive results as to the nature or causes of the problems experienced. ESD was of the opinion that with proper maintenance and monitoring of circuit parameters, conclusive data could be obtained.

The real issue appeared that further testing was required to define the problem. Furthermore, this testing would require additional funds above those already programmed and obligated. The cost of various solutions was dependent upon the problem and therefore total costs could not be fully determined at that time.

Air Staff Guidance

As a result of the October 2-3, 1975, meeting, the Air Staff requested that AFSC as lead command, and with participating commands, determine the operational impact, scheduling and funding requirements needed to complete the implementation of WGS. The Air Staff also requested that alternatives to satisfying the AWS weather dissemination requirement be addressed and life cycle costs determined. The evaluation life cycle costs were to cover a six/ten year period.[3]

The results of the AFSC tasking were briefed to the Air Staff on December 19, 1975. The ten year life cycle costs for WGS were as follows:[4]

DEPOT (AFLC)	$4,479,000
CIMF* (AFCS)	594,000
Training	2,697,000
Traveling Maintenance Team	1,752,000

*Consolidated Intermediate Maintenance Facility

Complete Installation	$1,752,000
European Test	392,000
Total	$10,139,000

(9 Transmitters, 108 Receivers, 16 Regenerators, 56 receive locations)

The alternative involved an analog facsimile model DL-19W manufactured by Datalog and leased to the Air Force as a replacement for RJ-4 in the continental United States and Pacific areas. The ten year life cycle cost for the analog DL-19W alternative was as follows:[5]

Equipment Leasing	$2,691,000
Maintenance	1,825,000
Training	661,000
Expendables	830,000
Spare Kit Replenishment	13,000
European Test	53,000
Total	$6,073,000

(Four Transmitters, 93 Receivers, Support Equipment)

The cost differential between digital WGS and the analog facsimile alternative amounted to $4,066,000. This did not include the price of a corrective modification, since the problem was undefined.

In developing the analog alternative, AWS lowered their facsimile speed requirement to 2:1 versus 3:1 for WGS.[6] At this scan speed the DL-19W has a resolution

of 96 lines per inch versus the WGS 100 lines per inch. During an opportune moment on October 3, 1975, the HQ USAF representative requested, witnessed and was provided an IEEE facsimile test chart processed through the WGS equipment. An interpretation of the IEEE facsimile chart indicated a maximum resolution of 70 lines per inch.[7] Contractor personnel pointed out that the equipment had not been recently aligned since this was a random and somewhat unexpected event. By comparison, the operating MUFAX analog equipment in Europe was at best providing 48 lines per inch at 120 scans per minute, the reference speed. MUFAX is rated at 96 lines per inch at 60 scans per minute.

The implementation schedule briefed to the Air Staff showed that DL-19W installation could be completed in ten months vice twelve months for WGS once approval was issued. Other factors favorable to the DL-19W alternative were that it was easy to maintain, it was not as sensitive to communication line anomalies, and it would standardize the AWS network worldwide.

Additional Alternative Guidance

Based on this briefing, the Air Staff on December 23, 1975, directed that AFCS with assistance from MAC/AWS, evaluate DL-19W equipment operation in Europe and provide a recommendation whether to continue with the WGS

project.[8] Another request by Air Staff issued January 20, 1976, to HQ AFSC asked to determine the cost of providing an interface within the WGS equipment for an external commercial modem and the costs of verification tests in Europe.[9]

The evaluation of the DL-19W equipment in Europe was conducted during the period of February 5 to March 28, 1976. During the final phase of evaluation, all test charts were transmitted from AFGWC at Offutt AFB. In a twenty-four hour period a minimum of 100 test charts were transmitted at 240 scans per minute (2 to 1). The number of acceptable or usable charts (Grade 3 - excellent, and Grade 2 - usable) received during the final phases at designated European locations are expressed in percentages as shown below:[10]

Ramstein AB, Germany	100 percent
Mt. Limbrara, Italy	95 percent
Athens AB, Greece	76 percent
Incirlik AB, Turkey	67 percent
Torrejon AB, Spain	95 percent

In determining the cost of WGS interface for an external modem, the 433L SPO recommended a five-week mini-test in Europe. The test would evaluate the Codex 9600 and Codex 4800 modems and would cost $220,000.[11] The purpose was to select the best performing modem

since Rome Air Development Center in their work had concluded, "There is a significant increase in performance and cost in 9600 bit per second modems. Generally 9600 bit per second modems operating at 4800 bit per second are superior to stock 4800 bit per second modems."[12] The Codex modems were on a recommended list submitted by AFCS.[13] An unofficial estimate of the cost of modifying all WGS equipment for the external modem interface was $1,200,000 and $900,000, depending on whether a Codex 9600 or 4800 modem was used.[14] The costs of leasing or buying the external commercial modems would be additional to the modification costs of the interface. The cost of Codex 4800 modem was approximately $4,800; a total of 66 units would be required, one *for each terminal and two* for each regenerator site.

At the same time, both MAC(AWS) and AFCS agreed that the DL-19W facsimile equipment could satisfy the AWS mission of disseminating weather graphic products in Europe. Both commands recommended approval to proceed with the DL-19W implementation.[15]

The Final Decision

The Air Staff considered the DL-19W evaluation results, the WGS interface modification, and the costs of 66 external commercial modems. The ten-year life cycle

costs of WGS were recomputed, $12,000,000 using the Codex 9600 modem and $11,300,000 using the Codex 4800 modem vice $6,000,000 for the DL-19W analog facsimile alternative. The use of external commercial modems on WGS transmitters, receivers, and regenerators to overcome the data transmission difficulties was not a confirmed solution, and presented a risk of failure requiring a future commitment of additional funds. Continuing with WGS would cost between $5,000,000 to $6,000,000 over the alternative.[16] On the basis of cost saving, the technical risk, and the major command recommendation to implement the DL-19W equipment, the Air Staff approved the recommendation and terminated the WGS program on April 30, 1976.[17] The total WGS program cost between June 1967 and September 1975 incurred by the Air Force was $10,147,000. The cost breakout is detailed in Appendix E.

CHAPTER XIV

TWENTY/TWENTY HINDSIGHT

The failure of the WGS acquisition resulted from a lack of technical judgment on the part of the implementation management. This assertion is supported by management's inability to define the problem early in the acquisition process after contract award. A lack of technical judgment was demonstrated in understanding the basic elements of a communications system as described in Chapter I. This hindered a technical assessment of the operational requirement and means to minimize implementation risks.

The operational requirement for WGS approved in 1964 included a performance parameter of speed, or in more precise terms, an equivalent information transfer rate of five times that of the current systems. A technical assessment would have indicated that the risk in satisfying the operational requirement was in implementing the "information transfer" segment of the system. The design and fabrication of the terminal hardware functions, less the information transfer segment, presented negligible risk for implementation (as proven in a back-to-back operation of WGS).

The difficulty of this marriage between modem and circuit comprising the information transfer segment was confirmed by the failure of the WGS European Signature Tests and the final operational test. In an article appearing in Telecommunications, July 1973, titled "European Area Data Transmission Tests," the authors concluded that 4800 bit per second service was entirely feasible on the European System for dedicated applications.[1] It became apparent that a modem with a higher degree of circuit equalization capability would work, but at a greater cost to the Air Force.

The decision to include the modem as an integral part of the WGS terminal equipment doomed the acquisition from the start. After it was apparent the WGS modem would not provide an acceptable product to the user, implementation management did not explore the alternative of providing an interface for an external modem. According to Telecommunications, June 1971 issue, an industry periodical, there were only eighteen (18) manufacturers of 4800 bit per second modems in the United States.[2] AFCS issued a recommended list that contained five (5) modem models of different manufacturers and the WGS contractor was on neither list.[3]

A comment made by an RADC representative at the April 4, 1972, meeting prior to the European demonstration

in essence was that state-of-the-art for equipment susceptibility to impulse noise was much better (10 to 15 decibels) than for the EG&G modem.[4] Apparently this technical pronouncement went unheeded by WGS implementation managers and technical experts. At this point in time, a better modem from a reputable manufacturer and leader in the industry would have satisfied the requirement, or conversely eliminated all doubt and limited the problem to only the circuit. This alternative was not considered.

A reasonable conclusion is that acquisition of communications-electronics terminal equipment with a digital bit stream output or input greater than an arbitrary rate of 2400 bits per second should be specified without an internal modem, but with an interface for an external military or commercial modem. This will provide flexibility to the user in selecting or matching the appropriate modem to a particular grade communications circuit. It is interesting to note that the Tactical Digital Facsimile equipment being developed for DoD in the Joint Tactical Communications (TRI-TAC) Program does not include a modem. This is good technical judgment.

The operational requirement for WGS approved in November 1964 calling for a five to one speed increase

was ambitious and in the forefront of applied technology. The acceptance by AWS of the alternate solution of using DL-19W equipment with a transmission rate equivalent to 240 scans per minute, twice the system it replaced, was a tacit acknowledgment the original requirement was overstated. This does raise another question whether the WGS modem would have been acceptable at one-half speed, 2400 bits per second over European circuits. The WGS scan rate per minute was equivalent to 600. It follows that without FEC and FARL and the modem operating at half speed the WGS apparent scan rate would be 300. However, the closeness of the DL-19W scan rate of 240 does not negate the $4,000,000 advantage in ten year life cycle costs over WGS.

Another contributing factor in not recognizing the modem-communications channel dependency was the European Signature Test. The simulations were unrealistic for the following reasons:

1. The error introduction tapes (EIT) were reduced by an analysis computer with error determination, check error detection and resynchronism. The result was an optimistic EIT without the nominal modem and decoder anomalies.

2. Errors between the AFGWC and the European network were not electronically added into the simulation. Thus the results were optimistic.

3. Burst errors due to impulse noise and momentary dropouts were acknowledged but were not electronically simulated. Again the overall results were overly optimistic.

We can conclude that the methods used to simulate the WGS European operation with data obtained from the "Signature Tests" was not done in an objective manner. The results of the simulation reflected in the ESD report were in fact optimistic values. The simulation was not in reality a true electrical simulation of the European circuit environment. The assessment was confirmed by the WGS failure to transmit and receive an acceptable number of weather maps between Kindsbach and Rhein-Main AB.

In summary, an assessment of technical risk for the "information transfer segment" was not made in evaluating the original requirement or structuring the terminal equipment for an external modem. Secondly, the simulation of the European circuit environment did not reflect the expected high standards of professional objectivity.

APPENDIX A

TECHNICAL ASPECTS OF FACSIMILE

A general understanding of the technical aspects of facsimile operation will facilitate an appreciation of the problems faced by the acquisition program manager. Gadi Kaplan, an associate editor of *IEEE Spectrum*, September 1974, presented a brief but succinct article that is quoted in part:*

> Specifications of Fax Apparatus
>
> Fax transmitters and receivers are offered today by many vendors. Applications vary from weathermaps transmission to relay of police records and fingerprints. Specifications, too, vary accordingly. While an average office document can require a vertical resolution no greater than 60 to 90 lines per inch (lpi), upwards of 200 lpi is needed for police transmission of fingerprints. Scanning and transmission speeds are of great concern as well. In this respect, there is a marked difference between analog fax apparatus, where about three to six minutes are required for a transmission of a 8.5- by 11-inch standard office document, and its digital counterpart, doing the same job in a fraction of a minute.
>
> In an analog fax system, there is normally a tradeoff between scanning speed and the resolution. Some customers would prefer the faster machines, i.e., equipment with a three-minute or less scanning time for a standard page, while others may assign top priority to resolution. Some vendors, however, provide a selection of a few resolutions and speed values in one transceiver (a combined transmitting and receiving apparatus).
>
> About the highest transmission speed demonstrated to date in a digital fax system via

*Pp. 77-81.

voice-grade circuits is 15 seconds per "average" standard office document, and this has been achieved through use of a variable-velocity scanning technique in equipment now commercially available. Similarly, digital data-compression techniques, permit increased scan rate with no sacrifice of resolution.

To convert the information of the scanned page into a signal that can be transmitted over regular telephone lines (the so-called voice-grade circuits), and vice versa, a modulator and demodulator (modem) is required. Most modem equipment is designed for use on voice-grade circuits, but modulation techniques vary. While FM (amplitude modulation) is preferred by manufacturers of conventional analog equipment, digital data-compression techniques are fast catching on. But equipment using the latter techniques is naturally more expensive.

Coupling to the phone lines in facsimile transceivers is normally accomplished either through a specific data-access arrangement (DAA), usually leased from the phone company, or, as in the case in more conventional analog equipment, through acoustic coupling to the telephone receiver.

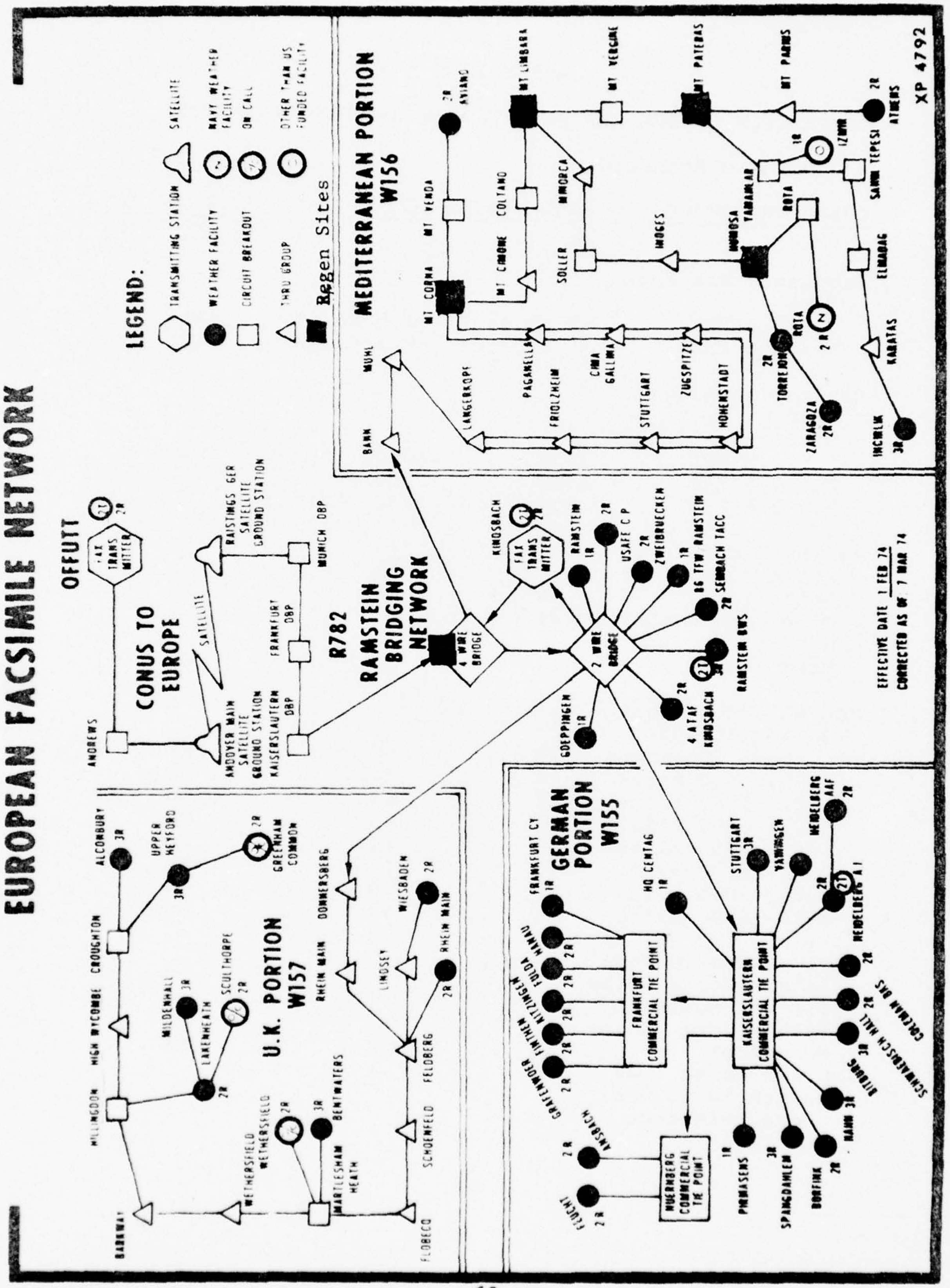
Analog Fax Transceivers How They Work.

The common phone-coupled analog fax transceiver designed as a business communication tool, is made of the following basic building blocks: (1) A scanning and recording mechanism. (2) A modulated oscillator and demodulator circuit. (3) Control logic. (4) Frequency standard for synchronization of transmission and reception. (5) A circuit coupling the transceiver to phone lines.

The scanner signal is used to modulate the oscillator (AM or FM) within the conventional telephone circuit bandwidth (roughly, 0.3 to 3.0 kHz). The typical system transmits at a speed of 180 scan lines per minute. At that speed, the system is able to resolve

about 100 picture elements (pels) along the scan axis (i.e., horizontally across the scanned document). At a vertical resolution of 100 scan lines per inch, an 8.5 x 11 inch document will be transmitted in about six minutes.

Initial "phasing" of the "send" and "receive" drums is achieved by the latter being held at a lower or higher speed until a received and a locally generated end-of-line pulse occur simultaneously. Both receiver and transmitter will now remain aligned through the transmission. To ensure alignment, the motors are energized from precision power supplies. Recording may be by one of several processes, e.g., electrolytic, electroresistive, electrostatic, electropercussive-all of which result in direct, permanent recordings, requiring no subsequent processing.


EUROPEAN FACSIMILE NETWORK
LEGEND:
TRANSMITTING STATION
WEATHER FACILITY
CIRCUIT BREAKOUT
THRU GROUP
Regen Sites
SATELLITE
NAVY WEATHER FACILITY
ON CALL
OTHER THAN US FUNDED FACILITY
OFFUTT
CONUS TO EUROPE
R782 RAMSTEIN BRIDGING NETWORK
U.K. PORTION W157
GERMAN PORTION W155
MEDITERRANEAN PORTION W156
FRANKFURT COMMERCIAL TIE POINT
KAISERSLAUTERN COMMERCIAL TIE POINT
NUERNBERG COMMERCIAL TIE POINT
EFFECTIVE DATE 1 FEB 74
CORRECTED AS OF 7 MAR 74
XP 4792

APPENDIX C

COMPARISON OF DCA AND BELL SYSTEM CIRCUIT PARAMETERS

NS = No Standard

CHARACTERISTICS	BELL SYSTEM C2	DCA S2	BELL SYSTEM C2 SWITCHED
Frequency Response (db)			
0.3-3.0 KHz	-2 to +6	-1.5 to -4.5	NS
0.5-2.8 KHz	-1 to +3	-0.5 to -2	NS
Maximum Envelope Delay Distortion (USEC)			
0.5-2.8 KHz	3000	1500	1500
0.6-2.6 KHz	1500	750	750
1.0-2.6 KHz	500	250	250
Max Net Loss Variation (db)	NS	±3	NS
Short Term	±3	NS	NS
Short and Long Term	±4	NS	NS
Max Change in Audio Frequency (Hz)	±10	±5**	NS
Max Allowable Chnl Noise (dbrncØ)			
0- 50 miles	31	NS	NS
51- 100 miles	34	34	NS
401- 1000 miles	41	41	NS
1001- 1500 miles	43	43	NS
1501- 2500 miles	45	45	NS
2501- 4000 miles	47	47	NS
4001- 8000 miles	NS	50	NS
8001-16000 miles	NS	53	NS
Maximum Single Tone Interference Below Circuit Noise in Each Mileage Category (db)	NS	3	NS
Impulse Noise (max counts in 15 min. above reference levels)	***		

CHARACTERISTICS	BELL SYSTEM C2	DCA S2	BELL SYSTEM C2 SWIT
Ref. level 71 dbrn CØ or 72 dbrn Ø voice band weighted	15	15	NS
Ref. level 62 dbrn Ø voice band weighted	NS	NS	NS
Terminal Impedance 600 ohm (% tolerance) Note 3.	NS	± 10	NS
Composite data transmission level (dbm Ø)	-12	-13	NS
Phase jitter peak to peak (degrees)	NS	15	NS
Harmonic distortion Note 4.	NS	-40	NS

** Circuits within CONUS ± 3Hz

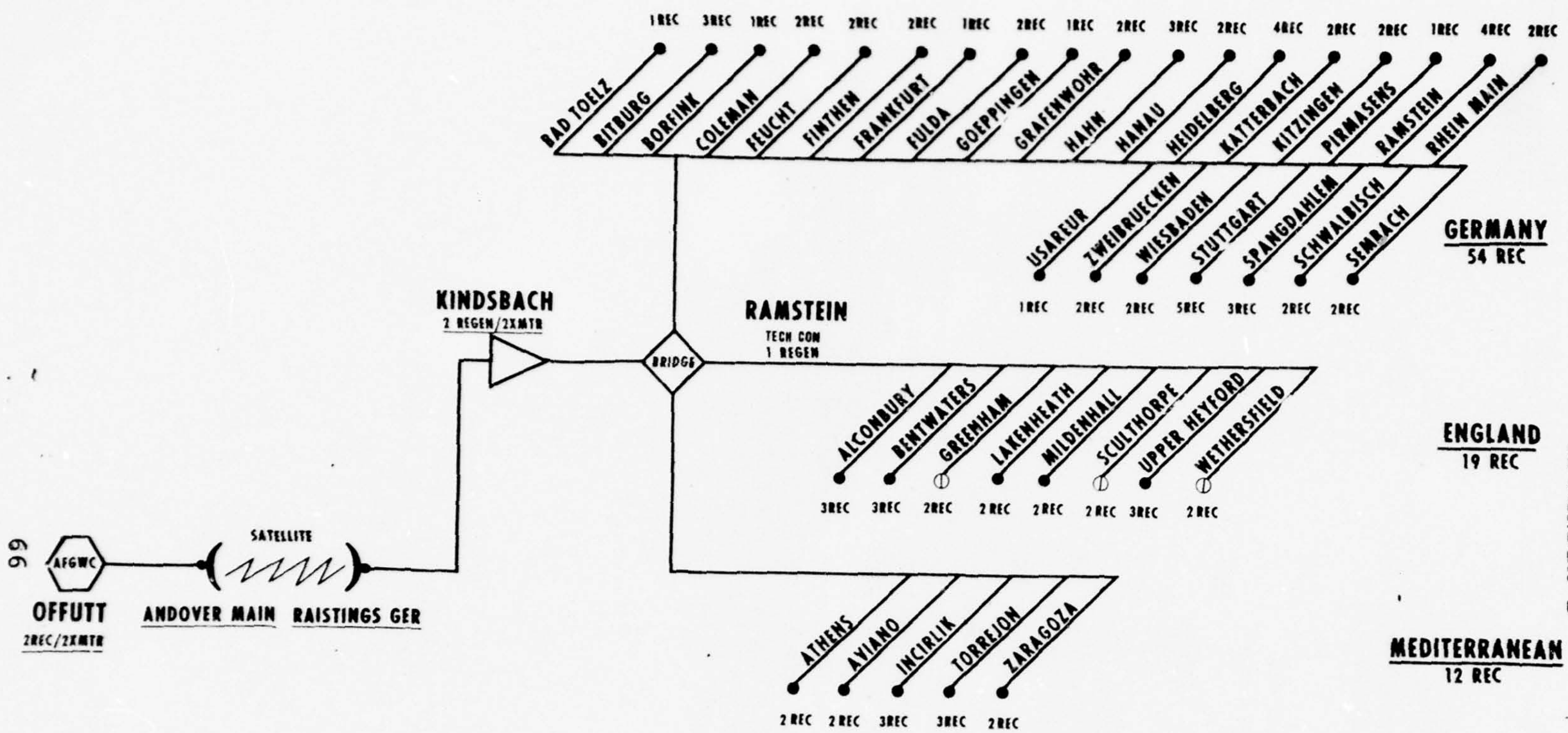
***Noise/background noise–the average noise power at the receiver terminal as measured with no frequency weighting shall not exceed -42 dbm.

Note 3. For leased circuits measured at 100 Hz; for government-owned circuits measured across the frequency band of interest.

Note 4. Applies to the measurement of any of the harmonies of a test frequency of 700 H_z introduced at a level of 10 dbmØ.

APPENDIX D

WEATHER GRAPHICS SYSTEM (WGS)



PROPOSED REGENERATOR SITES

- HILLINGDON
- MT LIMBARA
- MT PATERAS
- MT HUMOSA
- KINDSBACH

LEGEND

● WEATHER FACILITY

⦶ ON CALL FACILITY

	TOTAL
REC... AN/GMH-5A(V1) –	87
XMTR ... AN/GMT-3A –	4
REGEN. AN/GMH-5A(V2) –	11

SP 2812

AFCS PMD #74-2010-PC/(C3)
AS OF: February 1975

ATCH 5

APPENDIX E

WGS COST BREAKOUT

(APPROXIMATE)

June 1967 - September 1975

Basic Contract.	$ 6,880,000
Technical Orders.	60,000
Test Equipment.	50,000
Spare Parts	1,134,000
Type I Training (1971-72)	33,000
Total	$ 8,157,000
European Demonstration Test (1972).	79,000
European Signature Modem Test (1973).	472,000
Total	$ 551,000
WGS Storage	78,000
Modification Contract	996,900
Shipping Packing.	9,500
Total	$ 1,006,400
AFCS Engineering (including Ckt Cond)	81,000
AFCS Installation (labor)	43,000
AFCS Scheme Supporting Materials.	11,000
AFCS Shipping Supporting Materials.	6,000
Total	$ 141,000
ATC Training Costs (Feb - Sep 1975)	214,400
GRAND TOTAL	$10,147,800

NOTE: The tabulated monetary WGS costs of record are not complete. Many indirect and direct costs that the WGS program did absorb over the years are just not identifiable and/or available at this late date. Therefore, an accurate cost breakout of the overall WGS program may never be determined.

APPENDIX F

SIGNIFICANT MILESTONES

June 1959	Air Staff issues statement of requirement #175.
June 1967	WGS contract awarded to EG&G Incorporated, Bedford, Massachusetts.
January 1970 - January 1972	Category I Preliminary Qualification Tests performed.
March 1972 - August 1972	Category II Operational Tests performed.
September 1972	European Demonstration Tests held at Lindsey AS, GE.
August 1973	European Modem Signature Recording Effort.
February 1974	Air Staff directs deployment of WGS to Europe for replacement of the Muirhead Analog Facsimile System.
August 1974	WGS modification contract awarded to EG&G.
September 1975	Operational tests in Germany performed by AFCS.
October 1975	AFCS declares a moratorium on further installation of the Weather Graphics System.
December 1975	Air Staff directs WGS be retained in HIA status until testing of DL-19W is completed.
March 1976	AFCS completes testing of DL-19W recorder in Europe.

April 1976	AWS accepts deployment of DL-19W.
April 1976	CSAF/RDP terminates the WGS program and directs deployment of the DL-19W.
May 1976	AFCS cancels all work efforts on the WGS program and begins to dispose of all WGS equipment. Installation of the DL-19W schedule calls for completion during January 1977.

NOTES ON CHAPTER I

1. Daniel M. Costigan, "'Fax' in the Home: Looking Back and Ahead," IEEE Spectrum, September 1974, pp. 76-82.

2. "Specific Operational Requirement for an Improved Military Weather Observing and Forecasting System," S.O.R. No. 175, Director of Operational Requirements, Deputy Chief of Staff Programs and Requirements, United States Air Force, Washington, DC, January 13, 1959. Revised November 3, 1964. Hereafter cited as S.O.R. No. 175.

3. Ibid.

NOTES ON CHAPTER II

1. S.O.R. No. 175.

2. Ibid.

3. "Systems Program Directive for Weather Observation and Forecasting System (433L)," SPD No. 433L-1, Director of Systems Acquisition Office, Deputy Chief of Staff, Systems and Logistics, United States Air Force, Washington, DC, July 16, 1962, Revised September 30, 1963.

4. "Systems Program Directive Amendment (U) Weather Observation and Forecasting System 433L," SPD No. 433L-2, Letter of Director of Systems Acquisition Office, Deputy Chief of Staff Systems and Logistics, United States Air Force, Washington, DC, December 28, 1962.

5. "Systems Management Directive Weather Observing and Forecasting System," Headquarters United States Air Force, Directive Control Number SM6-18-433L(1)-Wx Obs Forecast, Director, Production and Programming, October 14, 1965.

6. "433L System Program Plan," Document of Director, Production and Programming, Air Force Systems Command, Andrews AFB, December 1, 1965, p. 12-2. Hereafter cited as 433L System Program Plan.

NOTES ON CHAPTER III

1. "Performance Specifications of AN/GMT-3 and AN/GMH-3," Letter of Assistant Deputy Chief of Staff Operations, Air Weather Service to 433L System Program Office, Electronic Systems Division, Air Force Systems Command, Scott AFB, March 24, 1966.

2. 433L System Program Plan, pp. 6-18 and 6-19.

3. "Performance Specifications of AN/GMT-3 and AN/GMH-3."

4. Ibid.

NOTES ON CHAPTER IV

1. "Weather Graphics System (WGS) Program Status and Schedule," Letter of System Program Director, Surveillance and Instrumentation System Program Office, Electronics System Division (AFSC), to all Air Force Project Officers, Hanscom Field, June 30, 1972, p. 19. Hereafter cited as <u>Weather Graphics System (WGS) Program Status and Schedule</u>.

2. Captain Stuart J. Evans, USN, Harold J. Margulis, and Harry B. Yoshpe, "National Security Management-Procurement," <u>Industrial College of the Armed Forces</u>, Washington, DC, 1968, p. 104.

3. Ibid.

4. Ibid.,p. 20.

5. "Request for Extraordinary Relief Under PL85-804, EG&G, Contract No. F19628-67-C-0347," Letter of Chief, Contract Claims and Opinions Branch, Office of the Staff Judge Advocate, Electronics Systems Division (AFSC), to Director of Procurement (OCP-3), Electronics System Division, Hanscom Field, June 10, 1975, p. 20.

6. <u>433L System Program Plan</u>, p. 12-2.

NOTES ON CHAPTER V

1. Victor M. Tyler, II, "Two Hardcopy Terminals for PCM Communication of Meteorological Products," [illegible] Incorporated, undated, p. 1.

2. Richard L. Petritz, "The Pervasive [illegible] Trends and Prospects," Institute of Electrical and Electronics Engineers Spectrum, July 1977, pp. [illegible].

3. W. Wesley Peterson, Error-Correcting Codes, Massachusetts Institute of Technology Press, Cambridge, Massachusetts, 1961, p. 3.

4. Robert A. Scholtz, "Codes with Synchronization Capability," IEEE Transactions on Information Theory, April 1966, pp. 135-142.

5. Charles A. Strom, Jr., "Communications Technology: 25 Years in Retrospect," IEEE Communications Society Magazine, September 1977, pp. 6-10.

6. R. W. Lucky, J. Salz, and E. J. Weldon, Jr., Principles of Data Communication, New York, McGraw-Hill Book Company, 1968, p. 123.

7. Ibid.

8. Allan B. Chertok, "A Multiple Speed Partial Response Modem Featuring A Unique SSB Modulation-Demodulation System," EG&G, Inc., 69CP[illegible]-COM, p. [illegible].

9. Subbarayan Pasupathy, "Correlative Coding: A Bandwidth-Efficient Signaling Scheme," IEEE Communications Society Magazine, July 1977, pp. [illegible].

10. Victor M. Tyler.

NOTES ON CHAPTER VI

1. "433L Personnel Subsystem Team Conference, Hanscom Field, Massachusetts, 13-14 May 1969," Trip Report of Communication Specialist, Base Facility Division to Director of Requirements, Deputy Chief of Staff Plans and Programs, Air Force Communications Service, Scott AFB, May 26, 1969.

2. "Final Category I Test Report for Weatherplotter Sets Transmitting, AN/GMT-3 and Receiving, AN/GMH-5," Report No. T-15-17-19-22, EG&G, Incorporated, Bedford, Massachusetts, December 5, 1972. p. 3-45.

3. Ibid., p. 1-1.

4. Ibid., pp. C-2 and C-10.

NOTES ON CHAPTER VII

1. "433L Weather Graphics System (WGS) Meeting," Letter of Chief, Base Facilities Division, Deputy Chief of Staff Plans and Programs, Air Force Communications Service to Weather Instrumentation System Program Office, Electronics System Division (AFSC) and Directorate Communications Requirements, Deputy Chief of Staff Systems, Air Weather Service, Richards-Gebaur AFB, January 19, 1972.

2. Category II Test Report for Weatherplotter Sets Transmitting, AN/GMT-3 and Receiving AN/GMH-5, Technical Report 395 by Deputy for Surveillance and Control Systems, Headquarters Electronics System Division, Hanscom Field, November 1972, p.1.

3. "Weather Graphics System Signal to Impulse Noise Limitations on C-2 Circuits," Message of Weather Instrumentation System Program Office, Electronics Systems Division (AFSC) to Base Facilities Division, Deputy Chief of Staff Plans and Programs, Air Force Communications Service, Hanscom Field, March 22, 1972.

4. Ibid.

5. Weather Graphics System (WGS) Program Status and Schedule.

6. Ibid.

7. "WGS Cat II Test Report Approval," Message of Directorate of Communications Requirements, Deputy Chief of Staff Systems, Air Weather Service to Ground Instrumentation Engineering and Test Division, Electronics Systems Division, Air Force Systems Command, Scott AFB, November 6, 1972.

8. "Results of OA Tests Conducted on 433L WGS with AFCS Test Team Which Participated in CAT II Tests," Letter of Electronics Engineer, Operations Research Analysis Office to Director Operations Research Analysis, Air Force Communications Service, Richards-Gebaur AFB, May 3, 1972. Hereafter cited as Results of OA Tests Conducted on 433L WGS.

9. Ibid.

10. "Transmittal/Approval of Minutes of Meeting on WGS/Comm Circuit Problem, 4 April 1972," Letter of System Program Director, Surveillance and Instrumentation System Program Office, Electronics System Division (AFSC) to Base Facilities Division, Deputy Chief of Staff Plan and Programs, Air Force Communications Service, and Directorate of Communications Requirements, Air Weather Service, Hanscom Field, April 17, 1972.

11. "Transmittal/Approval of Minutes of Meeting on WGS/Comm Circuit Problem, 4 April 1972," Letter of Director of Communications, Headquarters Air Weather Service to Ground Instrumentation Engineering and Test Division, Electronics System Division (AFSC), Scott AFB, April 24, 1972.

12. "Weather Graphics System Signal to Impulse Noise Limitations on C-2 Circuits."

NOTES ON CHAPTER VIII

1. Results of the QRCC of the European Weather Facsimile System, AFCS-1839EI-MEA-73-7, 1839 Electronics Installation Group, Keesler AFB, February 1, 1973.

2. "433L Weather Graphics System (WGS) Test," Letter of Assistant Chief of Staff Operations, Air Weather Service to Assistant for Weather, Deputy Chief of Staff Programs and Resources, United States Air Force, Scott AFB, July 27, 1973.

3. "433L Weather Graphics System Meeting Minutes, 17-18 Oct 72," Letter of Director of Requirements, Deputy Chief of Staff Plans and Programs, Air Force Communications Service to Facilities Management Division, Communications Directorate, Deputy Chief of Staff Systems, Air Weather Service, Ground Instrumentation Engineering and Test Division, Electronics Systems Division (AFSC), Richards-Gebaur AFB, November 3, 1972. Hereafter cited as 433L Weather Graphics System Meeting Minutes, 17-18 Oct 72.

NOTES ON CHAPTER IX

1. "Option Buy, AN/GMH-5 Receiver, Weather Graphics System," Message of Electronic System Division, Directorate of Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force to Weather Graphic System Project Officers in Air Force Communications Service, Air Weather Service, and Air Force Logistics Command, November 1, 1972.

2. William J. Becker, GS-14, "Memorandum For Record," Directorate of Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force, Washington, DC, November 16, 1972.

3. 433L Weather Graphics System Meeting Minutes, 17-18 Oct 72.

4. "433L Weather Graphics System (WGS) European Modem Signature Test Report," Message of Commander, Air Force Communications Service to Commander, Electronics System Division, Air Force Systems Command, Richards-Gebaur AFB, December 28, 1973. Hereafter cited as 433L Weather Graphics System (WGS) European Modem Signature Test Report, December 28, 1973.

5. "AWS Facsimile Requirements," Message of Chief of Staff, Air Force Communications Service to Assistant for Weather, Deputy Chief of Staff Plans and Resources, United States Air Force, and Commander Electronics Systems Division, Air Force Systems Command, Richards-Gebaur AFB, January 18, 1973.

6. "Request for NCA Engineering Participation, Europe Emergency CEIP for Upgrade of Weather Facsimile," Message of Deputy Director of Programs Support, Deputy Chief of Staff Engineering and Programs, Air Force Communications Service, to Director Engineering and Installation,Northern Communications Area, Richards-Gebaur AFB, December 29, 1972.

NOTES ON CHAPTER X

1. "Proposed 433L Weather Graphics System (WGS) Test," Message of Directorate Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force, to Chief of Staff Air Force Communications Service and Deputy Chief of Staff Systems, Air Force Systems Command, Washington, DC, January 29, 1973.

2. "433L Weather Graphics System (WGS) Test," Message of Directorate of Development and Acquisition, Headquarters United States Air Force to Deputy Chief of Staff Systems, Air Force Systems Command; Chief of Staff, Air Force Communications Service; Deputy Chief of Staff Systems, Air Weather Service, Washington, DC, March 23, 1973.

3. Interim Test Report for Weatherplotter Sets Transmitting, AN/GMT-3 and Receiving, AN/GMH-5, Paragraph 1bd of DI-T-3718, issued by Electronics System Division, Hanscom Field, October 23, 1973, p. 2.

4. "Proposed 433L Weather Graphics System (WGS) Test."

5. "433L Weather Graphics System (WGS) European Modem Signature Recording Effort Test Report," Letter of Weather Instrumentation System Program Director, Electronics System Division to Deputy Chief of Staff Plans and Resources, Air Force Communications Service, and Director, Communications Requirements, Air Weather Service, November 23, 1973, p. 13.

6. Ibid., p. 23.

7. Ibid., p. 27.

8. Ibid.

9. Results of the Conditioning of the European Weather Facsimile System and the Weather Graphics System Signature Tests, AFCS-1839EI-MEA-73-27, 1839 Electronics Installation Group, Keesler AFB, November 14, 1973.

NOTES ON CHAPTER XI

1. "433L Weather Graphics System (WGS) European Modem Signature Test Report," December 28, 1973.

2. "433L Weather Graphics System (WGS) European Modem Signature Test Report," Message of Assistant DCS Plans and Resources, Air Force Communications Service to Headquarters United States Air Force and the Weather Instrumentation System Program Office, Electronics Systems Division, Richards-Gebaur AFB, January 8, 1974.

3. "WGS Deployment Recommendation," Message of Directorate of Communications Requirements, Deputy Chief of Staff Systems, Air Weather Service to Assistant for Weather, Deputy Chief of Staff Programs and Resources, United States Air Force, Scott AFB, January 14, 1974.

4. "433L Weather Graphics System (WGS)," Message of Program Control Office, Deputy Chief of Staff Systems, Air Force Systems Command to Electronics System Division, Directorate of Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force, Andrews AFB, January 29, 1974.

5. "433L Program Management Review," Letter of Chief, Ground Instrumentation Engineering and Test Division, Weather Instrumentation SPO, Headquarters Electronic Systems Division to All Attendees, Hanscom Field, February 12, 1974.

6. "Weather Graphics System Program Review," Letter of Operations Research Analysis Office to Directors of Plans and Resources, Engineering and Installations, Operations and Logistics, Air Force Communications Service, Richards-Gebaur AFB, February 8, 1974.

7. "Weather Graphics System Revised PMD," Message of Programs and Engineering Branch, Directorate of Command Control and Communications, Deputy Chief of Staff Programs and Resources, Headquarters United States Air Force, to Director Plans and Resources, Air Force Communications Service, Washington, DC, February 15, 1974.

8. "Supply of 'MUFAX' Spares," Letter of Chief Procurement Division, USAFE Region-UK, United States Air Force in Europe, to Deputy Chief of Staff for Engineering and Programs, Air Force Communications Service, Wiesbaden AB, March 12, 1974.

NOTES ON CHAPTER XII

1. "Weather Graphics System (WGS)," Message of Deputy Director of Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force to Deputy Chief of Staff Systems, Air Force Systems Command, April 16, 1974.

2. "Weather Graphics System (WGS) Modification Contract," Message of 433L System Program Director, Weather Instrument SPO, Electronics Systems Division, to Deputy Chief of Staff of Engineering and Programs, Air Force Communications Service, Hanscom Field, May 7, 1974.

3. "European Deployment of Weather Graphics System (WGS)," Message of Electronic Systems, Deputy Chief of Staff Systems, Air Force Systems Command to Chief of Staff, Air Weather Service, Andrews AFB, December 3, 1974.

NOTES ON CHAPTER XIII

1. "WGS Conference 2-3 Oct 75," Letter of Chief, Tracals Division, Deputy Chief of Staff Engineering and Programs, Headquarters Air Force Communications Service to All Air Force Participants in the WGS Acquisition Program, Richards-Gebaur AFB, November 14, 1975.

2. Ibid.

3. "433L Weather Graphics System (WGS)," Letter of Deputy Director of Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force to Deputy Chief of Staff Systems, Air Force Systems Command, Deputy Chief of Staff Maintenance Management, Air Force Logistics Command, Deputy Chief of Staff Engineering and Programs, Air Force Communications Service, Director Communications and Electronics, Air Training Command, Deputy Chief of Staff Plan and Programs, Operations, Military Air Command, Washington, DC, October 16, 1975.

4. "Performance and Cost Trade-Off of Existing Digital vs Analog Systems," Briefing of Chief, Solar and Atmospheric Engineering and Test Division, Electronics Systems Division, Air Force Systems Command to Headquarters United States Air Force, Washington, DC, December 19, 1975, p. 10.

5. Ibid., p. 11.

6. "Analysis of Weather Fax Systems for Europe," Message of Directorate Communications Requirements, Deputy Chief of Staff Systems, Air Weather Service to Weather Instrumentation System Program Director, Electronic Systems Division, Scott AFB, November 14, 1975.

7. Facsimile Test Chart, The Institute of Electrical and Electronics Engineers, Incorporated, New York, October 3, 1975.

8. "433L Weather Graphics System (WGS)," Message of Director Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force to Air Force Communications Service, Air Force Systems Command, and Military Air Command, Washington, DC, December 23, 1975.

9. "433L Weather Graphics System (WGS)," Message of Director of Development and Acquisition, Deputy Chief of Staff for Research and Development, United States Air Force to Deputy Chief of Staff for Systems, Air Force Systems Command, Washington, DC, January 20, 1976.

10. "DL-19W Testing In Europe," Message of Transmission Systems Division, Directorate of Systems Evaluations, Air Force Communications Service to Directorate of Communications Requirements, Deputy Chief of Staff Systems, Air Weather Service, Richards-Gebaur AFB, April 5, 1976.

11. "433L Weather Graphics," Message of Solar and Atmospheric Engineering and Test Division, Electronic Systems Division (AFSC) to Directorate of Electronic Systems, Deputy Chief of Staff Systems, Air Force Systems Command, Hanscom Field, March 23, 1976.

12. "Commercial Modem Information for Weather Graphics System (WGS)," Message of Director Communications Laboratories, Rome Air Development Center, Air Force Systems Command to Chief, Solar and Atmospheric Engineering and Test Division, Electronics Systems Division, Air Force Systems Command,Griffiss AFB, February 13, 1976.

13. "433L Weather Graphics System (WGS)," Message of Chief, Tracals Division, Deputy Chief of Staff for Engineering and Programs, Air Force Communications Service to Chief, Solar and Atmospheric Engineering and Test Division, Electronics System Division, Air Force Systems Command, Richards-Gebaur AFB, February 3, 1976. Hereafter cited as 433L Weather Graphics System (WGS), February 3, 1976.

14. "433L Weather Graphics."

15. "Evaluation of the DL-19W Facsimile Recorder in Europe (5 Feb-28 Mar 76)," Message of Deputy Chief of Staff for Engineering and Programs, Air Force Communications Service to Directors of Command Control and Communications Development and Acquisition, Maintenance Engineering and Supply, Assistant for Weather, Headquarters United States Air Force, Richards-Gebaur AFB, April 21, 1976.

16. "Weather Graphics System," Staff Summary Sheet of Chief, Engineering and Programs Branch, Plans and Programs Division to Directors of Command Control and Communications,

Development and Acquisition, Maintenance Engineering and Supply, Assistant for Weather, Headquarters United States Air Force, Washington, DC, undated.

17. "Weather Graphics System (WGS)-433L," Message of Deputy Director of Development and Acquisition, Headquarters United States Air Force to Headquarters Air Force Communications Service and Air Force Systems Command, Washington, DC, April 30, 1976.

NOTES ON CHAPTER XIV

1. Richard A. Northrup, Captain George E. Carter, USAF, and Jerrold W. Shipman, "European Area Data Transmission Tests," _Telecommunications_, July 1973, pp. 33-36.

2. Richard A. Borysiewicz, "The Modem In the Data Communication System," _Telecommunications_, June 1971, pp. 12-22.

3. _433L Weather Graphics System (WGS), February 3, 1976_.

4. _Results of OA Tests Conducted on 433L WGS_.

BIBLIOGRAPHY

"Analysis of Weather Fax System for Europe," Message of Directorate Communications Requirements, Deputy Chief of Staff Systems, Air Weather Service to Weather Instrumentation System Program Director, Electronic Systems Division, Scott AFB, November 14, 1975.

"AWS Facsimile Requirements," Message of Chief of Staff, Air Force Communications Service to Assistant for Weather, Deputy Chief of Staff Plans and Resources, United States Air Force, and Commander Electronics Systems Division, Air Force Systems Command, Richards-Gebaur AFB, January 18, 1973.

Becker, William J., GS-14, "Memorandum For Record," Directorate of Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force, Washington, DC, November 16, 1972.

Bristol, Thomas W., "SAW Devices and Applications-A Status Report," Microwave Journal, December 1977.

Category II Test Report for Weatherplotter Sets Transmitting, AN/GMT-3 and Receiving AN/GMH-5, Technical Report 395 by Deputy for Surveillance and Control Systems, Headquarters Electronics Systems Division,Hanscom Field, November 1972.

Chertok, Allan B., "A Multiple Speed Partial Response Modem Featuring A Unique SSB Modulation-Demodulation System," EG&G, Incorporated, 69CP366-COM.

"Commercial Modem Information for Weather Graphics System (WGS)," Message of Director Communications Laboratories, Rome Air Development Center, Air Force Systems Command to Chief, Solar and Atmospheric Engineering and Test Division, Electronics Systems Division, Air Force Systems Command,Griffiss AFB, February 13, 1976.

Costigan, Daniel M., "'Fax' in the home: looking back and ahead," IEEE Spectrum, September 1974.

"DL-19W Testing In Europe," Message of Transmission Systems Division, Directorate of Systems Evaluations, Air Force Communications Service to Directorate of

Communications Requirements, Deputy Chief of Staff Systems, Air Weather Service, Richards-Gebaur AFB, April 5, 1976.

"European Deployment of Weather Graphics System (WGS)," Message of Electronic Systems, Deputy Chief of Staff Systems, Air Force Systems Command to Chief of Staff, Air Weather Service, Andrews AFB, December 3, 1976.

"Evaluation of the DL-19W Facsimile Recorder in Europe (5 Feb-28 Mar 76)," Message of Deputy Chief of Staff for Engineering and Programs, Air Force Communications Service to Directors of Command Control and Communications, Development and Acquisition, Maintenance Engineering and Supply, Assistant for Weather, Headquarters United States Air Force, Richards-Gebaur AFB, April 22, 1976.

Evans, Captain Stuart J., Harold J. Margulis, and Harry B. Yoshpe, "National Security Management-Procurement," Industrial College of the Armed Forces, Washington, DC, 1968.

"Facsimile Test Chart," The Institute of Electrical and Electronics Engineers, Incorporated, New York, October 3, 1975.

"Final Category I Test Report for Weatherplotter Sets Transmitting, AN/GMT-3 and Receiving, AN/GMH-5," Report No. T-15-17-19-22, EG&G, Incorporated, Bedford Massachusetts, December 5, 1972.

Holsinger, Jerry L., "Where Are Modems Going," IEEE Communications Society Magazine, September 1977.

Interim Test Report for Weatherplotter Sets Transmitting, AN/GMT-3 and Receiving, AN/GMH-5, Paragraph 1bd of DI-T-3718, issued by Electronics Systems Division, Hanscom Field, October 23, 1973.

"IRE Standards On Facsimile: Definitions of Terms, 1956," Proceeding of the I.R.E., June 1956.

Kaplan, Gadi, "Fax: Specs and Projections," IEEE Spectrum, September 1974.

Lucky, R. W., J. Salz and E. J. Weldon, Jr., Principles of Data Communication, New York, McGraw-Hill Book Company, 1968.

Northrup, Richard A., Captain George E. Carter, and Jerrold W. Shipman, "European Area Data Transmission Tests," Telecommunications, July 1973.

Northrup, Richard A. and Lt George E. Carter, "9.6 KBPS Modem and Circuit Tests," Telecommunications, June 1971.

"Option Buy, AN/GMH-5 Receiver, Weather Graphics System," Message of Electronic Systems Division, Directorate of Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force to Weather Graphics System Project Officers in Air Force Communications Service, Air Weather Service, and Air Force Logistics Command, November 1, 1972.

Pasupathy, Subbarayan, "Correlative Coding: A Bandwidth-Efficient Signaling Scheme," IEEE Communications Society Magazine, July 1977.

"Performance and Cost Trade-Off of Existing Digital vs. Analog Systems," Briefing of Chief, Solar and Atmospheric Engineering and Test Division, Electronic Systems Division, Air Force Systems Command to Headquarters United States Air Force, Washington, DC, December 19, 1975.

"Performance Specifications of AN/GMT-3 and AN/GMH-3," Letter of Assistant Deputy Chief of Staff Operations, Air Weather Service to 433L System Program Office, Electronic Systems Division, Air Force Systems Command, Scott AFB, March 24, 1966.

Peterson, W. Wesley, Error-Correcting Codes, Massachusetts Institute of Technology Press, Massachusetts, Cambridge, 1961.

Petritz, Richard L., "The Pervasive Microprocessor; Trends and Prospects," Institute of Electrical and Electronics Engineers Spectrum, July 1977.

"Proposed 433L Weather Graphics System (WGS) Test," Message of Directorate Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force, to Chief of Staff Air Force Communications Service and Deputy Chief of Staff Systems, Air Force Systems Command, Washington, DC, January 29, 1973.

"Request for Extraordinary Relief Under PL85-804, EG&G, Contract No. F19628-67-C-0347," Letter of Chief, Contract Claims and Opinions Branch, Office of the Staff Judge Advocate, Electronics Systems Division (AFSC), to Director of Procurement (OCP-3), Electronics Systems Division, Hanscom Field, June 10, 1975.

"Request for NCA Engineering Participation, Europe Emergency CEIP for Upgrade of Weather Facsimile," Message of Deputy Director of Programs Support, Deputy Chief of Staff Engineering and Programs, Air Force Communications Service, to Director Engineering and Installations, Northern Communications Area, Richards-Gebaur AFB, December 29, 1972.

"Results of OA Tests Conducted on 433L WGS with AFCS Test Team Which Participated in CAT II Tests," Letter of Electronics Engineer, Operations Research Analysis Office to Director Operations Research Analysis, Air Force Communications Service, Richards-Gebaur AFB, May 3, 1972.

Results of the Conditioning of the European Weather Facsimile System and the Weather Graphics System Signature Tests, AFCS-1839EI-MEA-73-27, 1839 Electronics Installation Group, Keesler AFB, November 14, 1973.

Results of the QRCC of the European Weather Facsimile System, AFCS-1839EI-MEA-73-7, 1839 Electronics Installation Group, Keesler AFB, February 1, 1973.

Scholtz, Robert A., "Codes with Synchronization Capability," IEEE Transactions On Information Theory, April 1966.

------, "Maximal and Variable Word-Length Comma-Free Codes," IEEE Transactions On Information Theory, March 1969.

Shannon, C. E., "A Mathematical Theory of Communication," in David Slepian, ed., Key Papers in The Development of Information Theory, New York, The Institute of Electrical and Electronics Engineers, Inc., 1974.

"Specific Operational Requirement for an Improved Military Weather Observing and Forecasting System," S. O. R. No. 175, Director of Operational Requirements, Deputy Chief of Staff Programs and Requirements, United States Air Force, Washington, DC, January 13, 1959, revised November 3, 1964.

Strom, Charles A., Jr., "Communications Technology: 25 Years In Retorspect," IEEE Communications Society Magazine, September 1977.

"Supply of 'MUFAX' Spares," Letter of Chief Procurement Division, USAFE Region-UK, United States Air Force in Europe to Deputy Chief of Staff for Engineering and Programs, Air Force Communications Service, Wiesbaden AB, March 12, 1974.

"Systems Management Directive Weather Observing and Forecasting System," Headquarters United States Air Force, Directive Control Number SM6-18-433L(1)-Wx Obs Forecast, Director, Production and Programming, October 14, 1965.

"Systems Program Directive Amendment (U) Weather Observation and Forecasting System 433L," SPD No. 433L-2, Letter of Director of Systems Acquisition Office, Deputy Chief of Staff Systems and Logistics, United States Air Force, Washington, DC, December 28, 1962.

"Systems Program Directive for Weather Observation and Forecasting System (433L)," SPD No. 433L-1, Director of Systems Acquisition Office, Deputy Chief of Staff, Systems and Logistics, United States Air Force, Washington, DC, July 16, 1962, revised September 30, 1963.

"Telecommunications Fax Survey," Telecommunications, December 1972.

"Transmittal/Approval of Minutes of Meeting on WGS/Comm Circuit Problem, 4 Apr 1972," Letter of Director of Communications, Headquarters Air Weather Service to Ground Instrumentation Engineering and Test Division, Electronics System Division (AFSC), Scott AFB, April 25, 1972.

"Transmittal/Approval of Minutes of Meeting on WGS/Comm Circuit Problem, 4 April 1972," Letter of System Program Director, Surveillance and Instrumentation System Office, Electronics System Division (AFSC) to Base Facilities Division, Deputy Chief of Staff Plans and Programs, Air Force Communications Service, and Directorate of Communications Requirements, Air Weather Service, Hanscom Field, April 17, 1972.

Tyler, Victor M., II, "Two Hardcopy Terminals for PCM Communication of Meteorological Products," EG&G, Incorporated.

"Weather Graphics System Program Review," Letter of Operations Research Analysis Office to Directors of Plans and Resources, Engineering and Installation, Operations and Logistics, Air Force Communications Service, Richards-Gebaur AFB, February 8, 1974.

"Weather Graphics System Revised PMD," Message of Programs and Engineering Branch, Directorate of Command Control and Communications, Deputy Chief of Staff, Programs and Resources, Headquarters United States Air Force to Director Plans and Resources, Air Force Communications Service, Washington, DC, February 15, 1974.

"Weather Graphics System Signal to Impulse Noise Limitations On C-2 Circuits," Message of Weather Instrumentation System Program Office, Electronics Systems Division (AFSC) to Base Facilities, Deputy Chief of Staff Plans and Programs, Air Force Communications Service, Hanscom Field, March 22, 1972.

"Weather Graphics System," Staff Summary Sheet of Chief, Engineering and Programs Branch, Plans and Programs Division to Directors of Command Control and Communications, Development and Acquisition, Maintenance Engineering and Supply, Assistant for Weather, Headquarters United States Air Force, Washington, DC, undated.

"Weather Graphics System (WGS)-433L," Message of Deputy Director of Development and Acquisition, Headquarters United States Air Force to Headquarters Air Force Communications Service and Air Force Systems Command, Washington, DC, April 30, 1976.

"Weather Graphics System (WGS)," Message of Deputy Director of Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force to Deputy Chief of Staff Systems, Air Force Systems Command, April 16, 1974.

"Weather Graphics System (WGS) Modification Contract," Message of 433L Systems Program Director, Weather Instrument SPO, Electronics Systems Division, to Deputy Chief of Staff for Engineering and Programs, Air Force Communications Service, Hanscom Field, May 7, 1974.

"Weather Graphics System (WGS) Program Status and Schedule," Letter of System Program Director, Surveillance and Instrumentation System Program Office, Electronics System Division (AFSC), to all Air Force Project Officers, Hanscom Field, June 30, 1972.

"WGS Cat II Test Report Approval," Message of Directorate of Communications Requirements, Deputy Chief of Staff Systems, Air Weather Service to Ground Instrumentation Engineering and Test Division, Electronics Systems Division, Air Force Systems Command, Scott AFB, November 6, 1972.

"WGS Conference 2-3 Oct 75," Letter of Chief, Tracals Division, Deputy Chief of Staff Engineering and Programs, Headquarters Air Force Communications Service to all Air Force participants in the WGS Acquisition Program, Richards-Gebaur AFB, November 14, 1975.

"WGS Deployment Recommendation," Message of Directorate of Communications Requirements, Deputy Chief of Staff Systems, Air Weather Service to Assistant for Weather, Deputy Chief of Staff Programs and Resources, United States Air Force, Scott AFB, January 14, 1974.

"433L Personnel Subsystem Team Conference, Hanscom Field, Mass. 13-14 May 1969," Trip Report of Communication Specialist, Base Facility Division to Director of Requirements, Deputy Chief of Staff Plans and Programs, Air Force Communications Service, Scott AFB, May 26, 1969.

"433L Program Management Review," Letter of Chief, Ground Instrumentation Engineering and Test Division, Weather Instrumentation SPO, Headquarters Electronic Systems Division to All Attendees, Hanscom Field, February12, 1974.

"433L System Program Plan," Document of Director, Production and Programming, Air Force Systems Command, Andrews AFB, December 1, 1965.

"433L Weather Graphics," Message of Solar and Atmospheric Engineering and Test Division, Electronic Systems Division (AFSC) to Directorate of Electronic Systems, Deputy Chief of Staff Systems, Air Force Systems Command, Hanscom Field, March 23, 1976.

"433L Weather Graphics System Meeting Minutes, 17-18 Oct 72," Letter of Director of Requirements, Deputy Chief of Staff Plans and Programs, Air Force Communications Service to Facilities Management Division, Communications Directorate, Deputy Chief of Staff Systems, Air Weather Service, Ground Instrumentation Engineering and Test Division, Electronics Systems Division (AFSC), Richards-Gebaur AFB, November 3, 1972.

"433L Weather Graphics System (WGS)," Letter of Deputy Director of Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force to Deputy Chief of Staff Systems, Air Force Systems Command, Deputy Chief of Staff Maintenance Management, Air Force Logistics Command, Deputy Chief of Staff Engineering and Programs, Air Force Communications Service, Director Communications and Electronics, Air Training Command, Deputy Chief of Staff Plans and Programs, Operations, Military Air Command, Washington, DC, October 16, 1975.

"433L Weather Graphics System (WGS)," Message of Chief, Tracals Division, Deputy Chief of Staff for Engineering and Programs, Air Force Communications Service to Chief, Solar and Atmospheric Engineering and Test Division, Electronics Systems Division, Air Force Systems Command, Richards-Gebaur AFB, February 3, 1976.

"433L Weather Graphics System (WGS)," Message of Director Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force to Air Force Communications Service, Air Force Systems Command, and Military Air Command, Washington, DC, December 23, 1975.

"433L Weather Graphics System (WGS)," Message of Director of Development and Acquisition, Deputy Chief of Staff for Research and Development, United States Air Force to Deputy Chief of Staff for Systems, Air Force Systems Command, Washington, DC, January 20, 1976.

"433L Weather Graphics System (WGS)," Message of Program Control Office, Deputy Chief of Staff Systems, Air Force Systems Command to Electronics Systems Division, Directorate of Development and Acquisition, Deputy Chief of Staff Research and Development, United States Air Force, Andrews AFB, January 29, 1974.

"433L Weather Graphics System (WGS) European Modem Signature Recording Effort Test Report," Letter of Weather Instrumentation System Program Director, Electronics System Division to Deputy Chief of Staff Plans and Resources, Air Force Communications Service, and Director, Communications Requirements, Air Weather Service, November 23, 1973.

"433L Weather Graphics System (WGS) European Modem Signature Test Report," Message of Assistant DCS Plans and Resources, Air Force Communications Service to Headquarters United States Air Force and Weather Instrumentation Systems Program Office, Electronics Systems Division, Richards-Gebaur AFB, January 8, 1974.

"433L Weather Graphics System (WGS) European Modem Signature Test Report," Message of Commander, Air Force Communications Service to Commander, Electronics Systems Division, Air Force Systems Command, Richards-Gebaur AFB, December 28, 1973.

"433L Weather Graphics System (WGS) Meeting," Letter of Chief, Base Facilities Division, Deputy Chief of Staff Plans and Programs, Air Force Communications Service to Weather Instrumentation Systems Program Office, Electronics System Division (AFSC) and Directorate Communications Requirements, Deputy Chief of Staff Systems, Air Weather Service, Richards-Gebaur AFB, January 19, 1972.

"433L Weather Graphics System (WGS) Test," Letter of Assistant Chief of Staff Operations, Air Weather Service to Assistant for Weather, Deputy Chief of Staff Programs and Resources, United States Air Force, Scott AFB, July 27, 1973.

"433L Weather Graphics System (WGS) Test," Message of Directorate of Development and Acquisition, Headquarters United States Air Force to Deputy Chief of Staff Systems, Air Force Systems Command; Chief of Staff, Air Force Communications Service; Deputy Chief of Staff Systems, Air Weather Service, Washington, DC March 23, 1973.